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Hacking the Biological Clock p. 34

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MIT Technology Review

VOL. 120 NO. 1 JANUARY/FEBRUARY 2017

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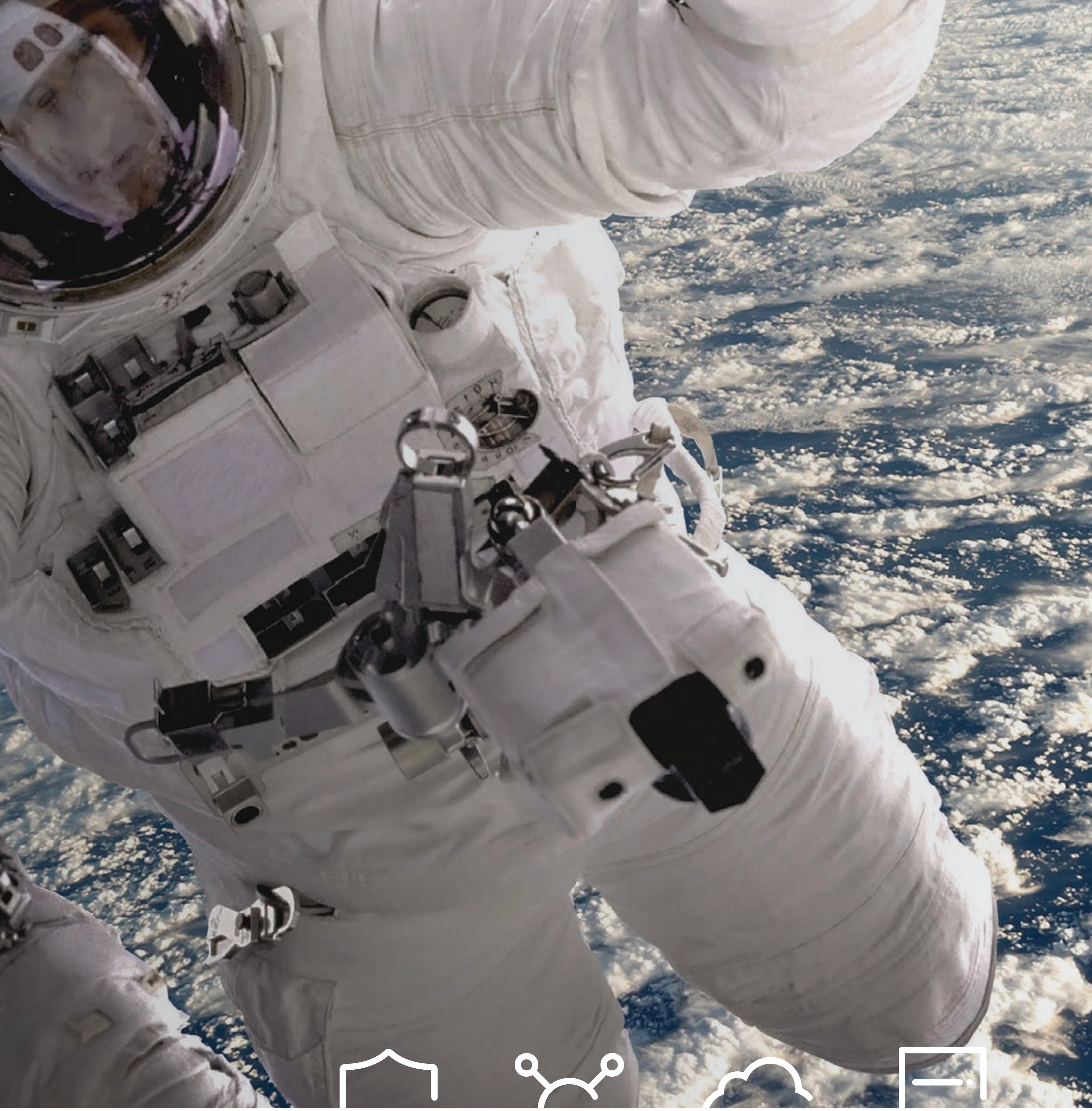

JUNIPER NETWORKS

From the Editor

Almost as soon as there was a World Wide Web, people worried about the "digital divide." In the summer of 1995, the new National Telecommunications and Information Administration published a report, "Falling through the Net: A Survey of the 'Have Nots' in Rural and Urban America." NTIA administrator Larry Irving and a White House aide named Albert Hammond began using the phrase to refer to inequality of access to information services. Vice President Al Gore spoke of it in his speeches.

More than 20 years later, it's easy to think that the digital divide has nearly closed, like a healing wound. In the United States, 88 percent of the population has Internet access of some sort;

globally, the figure is around 40 percent. According to various estimates, there will be more than six billion smartphones in the world by 2020, used by around 70 percent of the global population.

But even in the United States, as David Talbot writes in "The Hole in the Digital Economy" (see page 88), the poorest people, who might benefit most from Internet access, are often the least likely to have it.

Talbot writes, "Most homes in the United States have Internet service, but they don't in the poor parts of Cleveland … A survey in 2012 showed that 58 percent of the area's households with incomes under $20,000 had neither home broadband nor mobile Internet access, often because of the cost … Until recently, one such household was a ground-floor two-bedroom apartment in a public housing project called Outhwaite Homes, where a circumspect 13-year-old girl named Ma'Niyah Larry lives with her mother, Marcella."

Under a special-education plan to improve her mathematical skills, Ma'Niyah is supposed to solve problems and watch videos offered online by Khan Academy. But Marcella can't afford Time Warner's broadband fee of $50 a month, and although the family owns a smartphone, it's hard to solve problems on the tiny screen, and a few hours of math videos would exhaust their phone's data plan. The local library has high-speed Internet, but "it's so bad down here that it's not really safe to walk outside," Marcella says.

Digital evangelists once made strong claims for the economic and social benefits that would flow from closing the divide. Few experts are as confident today, but no one would dispute the assessment of the White House Council of Economic Advisers: "The digital divide is likely both a cause and a consequence of other demographic disparities." Without digital access, a long list of modern activities, including online education, are impossible. The digital divide separates and traps the poor.

Cleveland's public housing agency has given Ma'Niyah a tablet and a wireless hotspot in a trial to help close the "homework gap," but such pilot projects aren't a solution for thousands of families. Happily, a nonprofit named DigitalC plans to extend a fiber-optic network that connects Cleveland's hospitals (built with a 2009 federal stimulus grant) to the city's housing projects, using a millimeter-wave transmission system from a company called Siklu. The plan would bring gigabyte-per-second connections to the city's public housing, and in combination with an FCC subsidy, it would make broadband practical for most tenants in the projects.

That's good. But what about the millions in America's inner cities and rural communities who can't count on a project like Cleveland's DigitalC? The most plausible solution is to stimulate competition among broadband providers. Sometimes competition will be made possible by government investments in infrastructure: local, state, or federal monies would subsidize the building of fiber-optic networks. Sometimes governments can remove red tape to encourage investment: then any company, not just those that own physical conduits like utility poles, can easily add new fiber. Competition to reduce costs and increase speeds has narrowed the digital divide in a number of American cities, including Huntsville, Alabama, and Kansas City. Of course, the approach has any number of problems, especially in the countryside. But if we don't try, too many children like Ma'Niyah Larry will find it harder to learn.

Tell me what you think: write to me at jason.pontin@technologyreview.com.

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Letters and Comments

MIT Technology Review
Volume 119, Number 6

You Can't Avoid Failure Unless You Do Nothing

When J. P. Morgan funds Thomas Edison's work, or California VCs put money into a new venture, their motive is economic—to make a lot more money in the future than the original investment. That leads them to deep analysis of the economics of a proposed venture, and they fund only a carefully screened portion of all proposals.

Even so, some of them fail. The technology may not succeed. The R&D and execution costs may be much greater than estimated. The market may not exist as anticipated, or be much smaller, or be contested by direct competitors. The capitalists write off their investment and look for the next opportunity. Capitalists pick their investments carefully, and measure themselves by succeeding more often than they fail.

Government industrial policy, which David Rotman considered in "Capitalism Behaving Badly" (November/December 2016), follows a similar logic: it also would like to have more successes than failures. We accept that some ventures fail in the private sector, and that cleaning up is the responsibility of the capitalist. We are less ready to excuse failure of government-sponsored projects, and more likely to call for punishment of those responsible. Look at the development of the F35 VTOL fighter-bomber as a case in point.

We accept that some ventures fail in the private sector, and that cleaning up is the responsibility of the capitalist. We are less ready to excuse failure of government-sponsored projects, and more likely to call for punishment of those responsible.

A more fundamental problem is that the government sponsor's objective may not be economic at all, or only partially so. The objective may be the advancement of scientific knowledge, in the faith that history has demonstrated this is good for the nation. Or it may be military—the invention of solid-state electronic components and circuits needed for a ballistic missile system that does not yet exist. It may be a blend of ecological objectives and concern about limits on resources—development of liquid fuel from shale oil, or more fuel-efficient aircraft and autos. Or it may be social—accounting for externalities such as carbon emissions or creating employment at a living wage in ventures that at least also have some kind of economic usefulness (like the Tennessee Valley Authority).

If such noneconomic objectives are achieved, we can reckon such industrial policy a success. Their accounting may not be as crisp as that of P&L or IPO, but it is real nevertheless. And that may be the case in our government's battery and solar-cell ventures.

Industrial policy has its uses. Picking nothing but winners is impossible. Prudence, good management, and good luck will minimize the failures. But unless you do nothing, get used to the fact that there will be some.

Robert Garvin worked for General Electric for 42 years and is the author of Starting Something Big: The Commercial Emergence of GE Aircraft Engines. *He lives in Sarasota, Florida.*

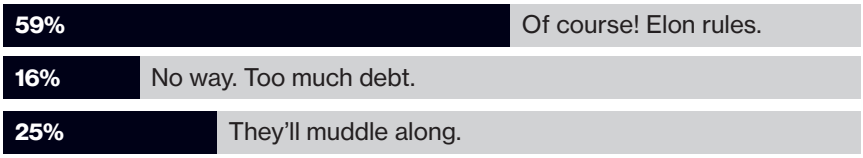
Correction

The number of electric cars on the road is around one million, not 100 million, as we incorrectly said in "Elon Musk's House of Gigacards" in November/December. The story also should have said 37 percent of U.S. homes are occupied by renters; it erroneously said 63 percent of U.S. homes are owned by a landlord or condo association.

Twitter Votes

Reactions to our stories on Elon Musk, Facebook in China, and self-driving Ubers.

Is Elon Musk's Tesla-SolarCity merger a brilliant strategic move?



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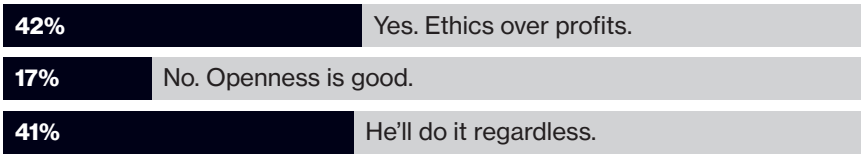

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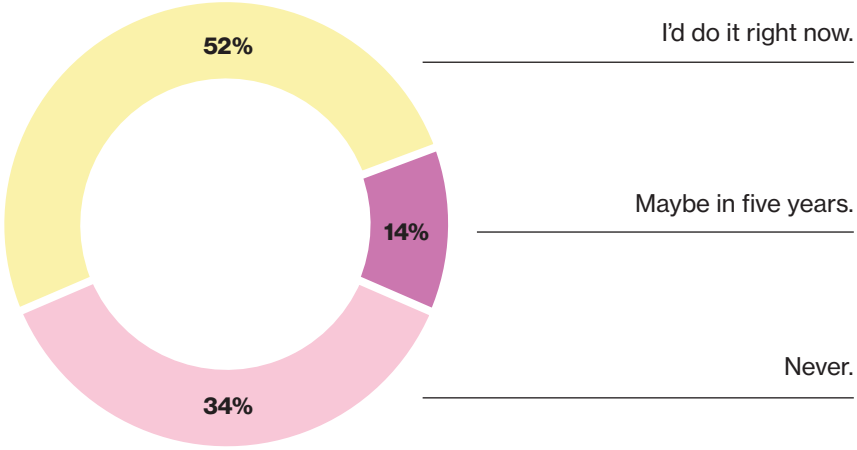

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Views

Four writers take on Trump and technology

MANUFACTURING

It's the Jobs, Stupid

Automation limits any president's ability to significantly boost factory employment.

Pundits will debate the wellsprings of Donald Trump's election triumph for years. Many journalists are stressing racial resentments and xenophobia, and while such explanations can't be dismissed, there's another issue that should be high on the list: the decades-long decline of U.S. manufacturing employment and the highly automated nature of the sector's recent revitalization.

The collapse of labor-intensive commodity manufacturing in recent decades and the expansion in this decade of superproductive advanced manufacturing have left millions of working-class people feeling abandoned, irrelevant, and angry. That rage helped get Trump elected. But the automated nature of advanced manufacturing means the president-elect won't be able to make America great again by bringing back production jobs.

The trends show a massive 30-year decline of employment beginning in 1980 that led to the liquidation of more than a third of U.S. jobs in manufacturing. Employment in the sector plunged from 18.9 million jobs to 12.2 million.

Much of the dislocation was concentrated in Midwestern and other Rust Belt states. This visited widespread havoc on blue-collar workers in manufacturing-oriented areas. Since 2000 alone, millions of workers have lost manufacturing jobs paying $25 per hour plus health and retirement benefits. Often the only alternatives were service-sector jobs without benefits paying $12 an hour.

As a consequence, there's been a sharp increase in political polarization in affected congressional districts—as demonstrated recently by MIT economist David Autor and his coauthors in a study of locations exposed to low-cost Chinese imports. There's a direct line between the loss of manufacturing jobs in those areas and Trump's election in November.

Manufacturing employment has in fact ticked up since 2010, reflecting the post-crisis auto boom and the relative strength of the nation's advanced manufacturing industries. But that hasn't mollified angry displaced workers. While it's encouraging for American competitiveness and some local clusters, the new growth has been too little, too late.

Trump has promised to bring back millions of jobs by renegotiating NAFTA, rejecting the Trans-Pacific Partnership, and slapping China with tariffs. But U.S. manufacturing has been succeeding by many measures in recent years, making Trump's promises seem like false dreams.

ANDY FRIEDMAN

In fact, the total inflation-adjusted output of the U.S. manufacturing sector is higher than ever. That's true even as the sector's employment is growing only slowly, and remains near the lowest it's ever been. These diverging lines—a result of improved productivity—highlight a huge problem with Trump's claims. America is *already* producing a lot. And in any event, the return of more manufacturing won't bring back many jobs, because the labor is increasingly being done by robots.

Boston Consulting Group reports that it costs barely $8 an hour to use a robot for spot welding in the auto industry. A human doing the same job costs $25 an hour—and the gap is only going to widen. The "job intensity" of America's manufacturing industries is only going to decline. In 1980 it took 25 jobs to generate $1 million in manufacturing output in the U.S. Today it takes five jobs. The hyperefficient shop floors of modern manufacturing won't give Trump much room to deliver on his promises.

So what's a more viable response to the plight of displaced workers? One response must be a forward-looking vision of what manufacturing has become (high tech, automated) to enhance American competitiveness. This means investing in manufacturing innovation to keep U.S. factories in the lead; ensuring that workers get industry-relevant training that equips them for today's digital factories; and supporting the nation's regional clusters of advanced industry, whether in Grand Rapids or Pittsburgh.

Yet no one should be under the illusion that millions of manufacturing jobs are coming back to America. Those who would help displaced workers need to think much more urgently about how to provide for what policymakers euphemistically call "adjustment" for the victims of economic shocks like deindustrialization.

Workers' frustrations with the massive changes in the manufacturing sector played a large role in determining the election results. Now it's going to take an unprecedented spirit of realism—about technology, about trade, about the inevitability of change—to address those frustrations.

Mark Muro is a senior fellow and the director of policy at the Metropolitan Policy Program at the Brookings Institution.

COMMUNICATIONS

Digitally Unequal

Poor areas have lousy Internet. Here's what Trump can do to help them.

The economic and democratic activities of American life now rely on advanced communications services—and there's a huge gap between those who get access to these services and those who don't. It springs from a lack of infrastructure investment in some parts of the country (see "The Hole in the Digital Economy," page 88).

And where are these places? It just so happens that the areas with the least investment in communications infrastructure, like fiber-optic cabling, are the same rural precincts that broke so strongly for Donald Trump in November.

Rural areas are typically served only by phone company infrastructure—aging copper networks. That means they've never benefited from competitive cable networks that could provide faster and cheaper access to the Internet. Some rural networks date back a century and are being shut down or neglected as phone companies find that their dollars can be spent more profitably elsewhere. Given the massive up-front investment that's necessary, there's simply not enough revenue potential in rural areas to justify the capital cost of upgrading networks.

President-elect Trump knows a thing or two about using tax, subsidy, and partnership strategies to get projects financed and built. Here are three ways he could use that knowledge to shrink the digital divide.

First, if Trump proposes a major infrastructure financing bill, as anticipated, he should include broadband infrastructure. Broadband deployment creates immediate construction jobs and also offers long-term economic benefits. High-speed Internet is the electricity of the 21st century—you don't get economic growth without it.

Second, he should expand the New Market Tax Credits program, which lets community development agencies in poor areas sell tax credits to private entities to help finance economic development projects (like new broadband infrastructure). This is a bipartisan program that generates more revenue than it costs. It gets investment into areas that would otherwise struggle to attract private capital.

Third, he should allow public-private entities to use tax-free municipal bonds to build communications infrastructure. Typically, such bonds can't be used for projects where a private entity will use whatever infrastructure ends up being built, and that rule is stifling development. Pikeville, Kentucky, is trying to finance the construction of a fiber-optic network that it would subsequently lease to private entities that could then offer services on the network (since the city doesn't want to be in the broadband business). Under the current rules, this kind of project can't be built with tax-free municipal bonds. Trump could change that.

The areas with the worst communications infrastructure broke strongly for Trump in November.

The president-elect has long been a builder of hotels, golf courses, and casinos. It's time he invested in the critical communications infrastructure necessary for economic growth in the rural areas that supported him so strongly.

Joanne Hovis is the CEO of the Coalition for Local Internet Choice and the president of CTC Technology & Energy.

ENVIRONMENT

Climate Control

Why a man who has called global warming a hoax might not harm the planet as many fear.

The Trump administration could be harmful to the planet. But it won't be fatal.

The harm will come from bombast and the inability of the United States to be a reliable partner and leader in international diplomacy. The Trump presidency will probably see the United States roll back payments to the climate regime—a treaty organized under the United Nations. The sums are relatively small (less than $3 billion initially) but politically essential to demonstrating that the United States is committed to the process.

Trump will also inflict harm by failing to provide leadership. The Paris agreement was successful in part because it papered over disagreements and pushed important tasks into the future. It works because it's a "pledge and review" system—it gives countries flexibility to set their own commitments but then reviews those efforts periodically to see what's working. The approach is highly suited to a problem like this—where many countries want to act but nobody is quite sure what's best—but it only works if there are serious reviews. It's unlikely that a Trump administration will foster good review

Views

mechanisms (see "Will the Climate Treaty Get the Money It Needs?" on page 26).

I'm not sure any other country will fill these gaps. The European Union might play a bigger role, but the EU's capacity to lead is hobbled by its own troubles—economic stagnation, divisions over immigration, Brexit. Norway will play a leadership role, as it always does, but country-wide reviews of economic policies don't let small countries effectively guide big countries (and big emitters). China may emerge as the de facto leader, partly because the pledge and review system suits its interests of wanting to show action without becoming encumbered by inconvenient international commitments. But before declaring that the climate is doomed, keep three things in mind.

First, nobody really knows Trump's views on climate change—perhaps not even Trump himself. Much has been made of his 2012 claim that the phenomenon is a "hoax" invented by the Chinese to steal American jobs, but that was a tweet—hardly the stuff of reasoned policy analysis.

Second, climate diplomacy under Trump could be a lot like that of the George W. Bush administration. One of Bush's first foreign policy actions was to abandon the Kyoto Protocol—a decision led by Vice President Dick Cheney, who was openly hostile to climate science. But quietly, the Bush team sought to build a climate policy based on coöperation in smaller groups rather than U.N. forums. It focused on innovation and deployment of new technologies. That approach was the right one, if not fully executed—and the Trump administration will find many allies ready to coöperate in small group settings.

Third, the effect that the U.S. has on the climate depends not just on leadership abroad but on policies at home. Here, Trump's impact will be a lot smaller than feared. Established policies like the Clean Power Plan will be hard for Trump to reverse unilaterally. Much of what the United States is actually doing on climate change is rooted in state policies and federal incentives—such as subsidies for renewable power—that are extremely popular and unlikely to change much. Nobody who closely studies U.S. energy markets thinks that Trump's bold claims of rebuilding the coal industry are serious.

At least for the next four years, the trajectory of U.S. emissions is unlikely to wiggle much no matter who sits in the White House. Trump isn't great news for the climate, but his administration may not be as toxic as people think.

David G. Victor is a professor at the University of California, San Diego, and co-chair of the Brookings Institution's Initiative on Climate and Energy.

SOCIAL MEDIA

A Smarter Web

In the age of Trump, we need more text and links, fewer images and memes.

Social media aided Donald Trump's election in ways that have nothing to do with fake news on Facebook.

In November 2014, I was freed after six years of incarceration in Tehran, a punishment I received for my online activism in Iran. Before I went to prison, I blogged frequently on what I now call the open Web: it was decentralized, text-centered, and abundant with hyperlinks to source material. It nurtured varying opinions.

Upon my release I found that the Web had changed radically. Facebook and Twitter had replaced blogging and had made the Internet like TV: centralized and image-centered, with content embedded in pictures, and without links.

Even more so than television, the Internet amplifies our existing beliefs. It makes us feel more than think, and it comforts more than it challenges. The result is a deeply fragmented society, radicalized by a lack of challenge from the outside.

In his illuminating 1985 book, *Amusing Ourselves to Death: Public Discourse in the Age of Show Business*, Neil Postman, a media critic at New York University, suggested that television turns news into disinformation. "Disinformation does not mean false information. It means misleading information—misplaced, irrelevant, fragmented or superficial information—information that creates the illusion of knowing something but which in fact leads one away from knowing ... Ignorance is always correctable. But what shall we do if we take ignorance to be knowledge?"

Today's Internet shares many of TV's ills and creates new ones. Social media uses algorithms to encourage comfort and complaisance, since its entire business model is built upon maximizing the time users spend inside it. Who wants to hang around in a place where everyone's mean and disapproving?

Trump's rise can't be reduced just to social media. Without income inequality, a shrinking middle class, and globalization, there would be no Trump or Brexit.

But we need to stop thinking that any evolution of technology is natural and therefore good. In social media's case, going backward would be a good thing: we need more text than videos in order to remain rational animals. We should write and read more, link more often, and spend less time on Facebook and Instagram.

We should actively expose ourselves to opposing views. We should follow people and pages that are not suggested to us. We should confuse the algorithms by liking what we dislike.

The idea of democracy founded on informed participation depends on it.

Hossein Derakshan is an Iranian-Canadian author, media analyst, and performance artist who lives in Tehran.

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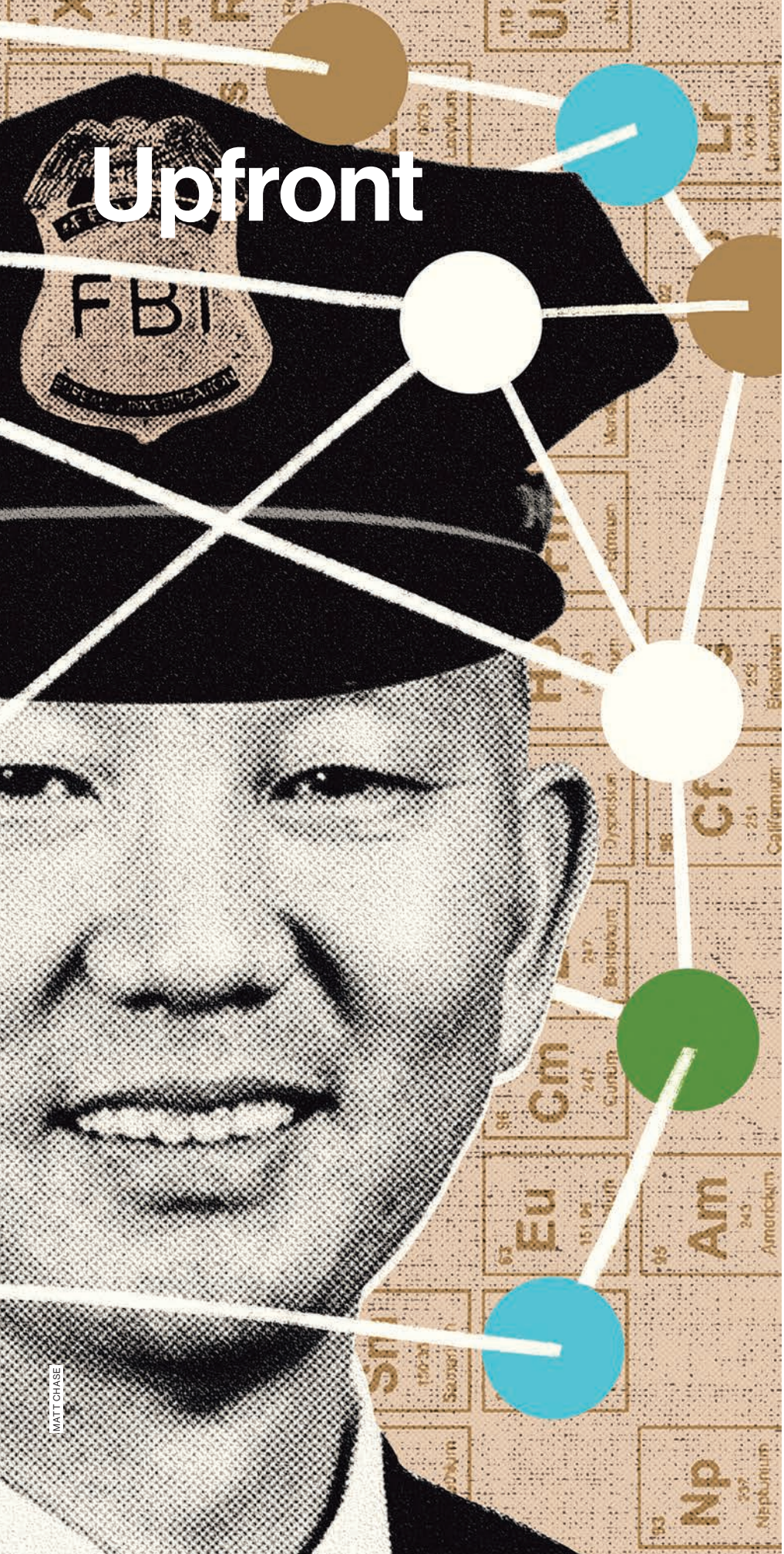

MATT CHASE

On Patrol with America's Top Bioterror Cop

Will garage gene editing unleash a biological plague? Special Agent Ed You is ready if it does.

Seen something strange growing in a petri dish in a friend's basement? Know an angry graduate student working odd hours in a pathogen lab? You might want to call Edward You.

As a supervisory special agent in the weapons of mass destruction directorate at the FBI's headquarters in Washington, D.C., You is effectively America's top biology cop. His job: track fast-moving developments in labs and make sure they don't lead to a bio-attack. It's a tough assignment. Methods of engineering microörganisms' DNA are readily available and getting more powerful. What's more, a new "do it yourself" movement is starting to shift genetic engineering out of large institutions and into DIY labs or people's homes, where it's harder to keep tabs on.

People who know him say You, who joined the FBI in 2005, has stretched the boundaries of his role at the agency, influenced policy makers to look at blind spots, and carried out a friendly, out-in-the-open campaign to infiltrate communities of "indie" biologists by getting to know them. You refers to his network of sources as a "web of detection" that allows him to learn what scientists are worried about. So far, he says, he hasn't been in any car chases. It is really more the biology equivalent of "911 calls about people driving recklessly," he says.

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You's approach is well tailored to the problem of biological threats. The challenge is that the same germs, techniques, and skills needed to study disease can also be used as weapons. In February, the U.S. declared gene editing with a technology called CRISPR, a new way of easily modifying DNA, to be a potential weapon of mass destruction. At the same time, home kits to modify the genes of bacteria using CRISPR are on sale online for $140.

That has created the theoretical possibility an evildoer could develop a deadly designer germ, or re-create an old one like smallpox. In practice, such engineering is not simple to do, but it may be in the near future. "Barriers to entry are lower for doing something malicious, and that jeopardizes all of us," says Nevin Summers, executive director of MIT's Synthetic Biology Center.

The FBI is a law enforcement and domestic intelligence agency. That means You is on the lookout more for homegrown biological Unabombers than for foreign agents. Bio-crime also remains very rare—though when it does happen, someone with scientific training is often to blame. In 1996, a laboratory technician at St. Paul Medical Center, Diane Thompson, told colleagues she'd left blueberry muffins and doughnuts in the kitchen. But she'd laced them with the bacteria *Shigella*, sending nine people to the hospital. The deadly 2001 anthrax attack through the U.S. postal system, the FBI concluded, was carried out by a mentally disturbed military scientist.

You says part of his role is to help scientists learn how to spot such "insider" threats. Attacks are often preceded by a suspect acting out in inappropriate e-mails or outbursts, working strange hours, or using too many supplies. Yet most academic biologists, working on curing cancer or devising new tests, are oblivious to the warning signs. "Preventing the misuse of technology is a shared responsibility," says You. "Now more than ever we need to have an army of white hats to be on the lookout for black-hat activity."

You was in action last fall during SynBioBeta, a two-day conference in San Francisco that draws a mix of large companies like DuPont, startups making lab-grown meat, and bio-hobbyists. He worked the room with handshakes and air kisses while his partner from the local FBI field office, a tattooed agent with a nose ring, handed out her card. "If there is anything you want to tell us, we can send it up to the mother ship in Washington," she told one entrepreneur.

You made himself known to the crowd while they milled around the coffee and cookies and ogled lab equipment on display. I asked if he came to such events armed. "We're all special agents," he answered ambiguously.

MATT CHASE

You earned a master's degree in molecular biology and later took a job at Amgen. Since joining the FBI he has also helped teach the government "to be less dumb" about biology, says Ken Oye, a political scientist at MIT. In 2004, the FBI showed just how poorly prepared it was when it detained a Buffalo bio-artist, Steve Kurtz, later charged under the Patriot Act, after finding bacterial cultures in his home. It was touted as a big blow against bioterrorism, but a judge eventually threw the case out as meritless. By 2009, the bureau had changed course. It began sponsoring the International Genetically Engineered Machine Competition, an annual fair where 3,000 student teams engineer microbes. And it courted DIY biologists, members of a counterculture movement whose projects include efforts to manufacture open-source insulin, dairy-free cheese, and other cheeky affronts to commercial biotechnology. Rather than persecute the group, which attracts its share of fringe characters, under You's direction the FBI has lent it credibility and sometimes financial support. Sebastian Cocioba, who operates a laboratory in a spare bedroom where he lives in New York, says he has a "go-to contact" in the FBI's regional field office.

Megan Palmer, a biosecurity scholar at Stanford University, says she refers people to You about twice a month. Those people have included a biotech company manager alarmed by a customer's questions and a person from the DIY community reporting an experiment that sounded troubling. You is often the first to hear about scientists' darkest worries. Lately some of these have been connected to CRISPR, which can be used to create DNA-slashing viruses or self-spreading gene alterations in insects. Another security risk that You has been looking into is connected to large DNA and biological databases.

One thing the FBI hasn't done is describe the results of its work. How many bio-threats are out there? How many get investigated? And how many originate inside government germ labs, which have a record of mishaps? You wouldn't describe any of his investigations, but he admits he is pursuing bio-threats that might never materialize. "A threat implies intent, and we haven't seen that yet," he says. "But as things become more widely available, more widely distributed, the bar gets lower, and the possibility of an incident gets higher." —*Antonio Regalado*


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Upfront

AI That Dreams Up Drugs

Ingesting a heap of drug data allows a machine-learning system to suggest alternatives humans hadn't tried yet.

What do you get if you cross aspirin with ibuprofen? Harvard chemistry professor Alán Aspuru-Guzik isn't sure, but he has trained software that could give him an answer by suggesting a molecular structure that combines properties of both drugs. The AI program could help the search for new drug compounds. Pharmaceutical research tends to rely on software that exhaustively crawls through giant pools of candidate molecules using rules written by chemists, and on simulations that try to identify or predict useful structures. The former approach requires humans to think of everything, while the latter is limited by the accuracy of simulations and the computing power required.

Aspuru-Guzik's system can dream up structures more independently of humans and without lengthy simulations. It leverages its own experience, built up by training machine-learning algorithms with data on hundreds of thousands of drug-like molecules. "It explores more intuitively, using chemical knowledge it learned, like a chemist would," says Aspuru-Guzik. "Humans could be better chemists with this kind of software as their assistant." Aspuru-Guzik was named to *MIT Technology Review*'s list of young innovators in 2010.

The new system was built using a machine-learning technique called deep learning, which has become pervasive in computing companies but is less established in the natural sciences. It uses a design known as a generative model, which takes in a trove of data and uses what it learned to generate plausible new data of its own. Last fall, Aspuru-Guzik and colleagues at Harvard, the University of Toronto, and the University of Cambridge published results after creating a generative model trained on 250,000 drug-like molecules. The system could generate plausible new structures by combining properties of existing drug compounds, and it could comply when asked to suggest molecules that strongly displayed certain properties.

The researchers have also experimented with training their system on a database of organic LED molecules, which are important for displays. But making the technique into a practical tool will require improving its chemistry skills, because the structures it suggests are sometimes nonsensical. Aspuru-Guzik hopes that giving his system more data will improve its power. *—Tom Simonite*

TO MARKET

Navdy

Windshield display

COMPANY:
Navdy

PRICE:
$799

AVAILABILITY:
Now

Heads-up displays for directions and notifications are trickling into luxury cars, but the $799 Navdy was born to be an aftermarket option. Its thin black base can be affixed to dashboards above the steering wheel, where it holds up a small transparent display. The screen floats, seemingly suspended against the bottom segment of the car's windshield. Enter a destination in Navdy's iPhone app, and directions appear on the display in what looks like a stripped-down version of Google Maps. The dream for heads-up displays is to place directions directly on the road in front of the driver. Navdy isn't there yet. Instead, it's meant to be an alternative to glancing down at a phone. *—Signe Brewster*

ROMAN MURADOV; COURTESY OF NAVDY

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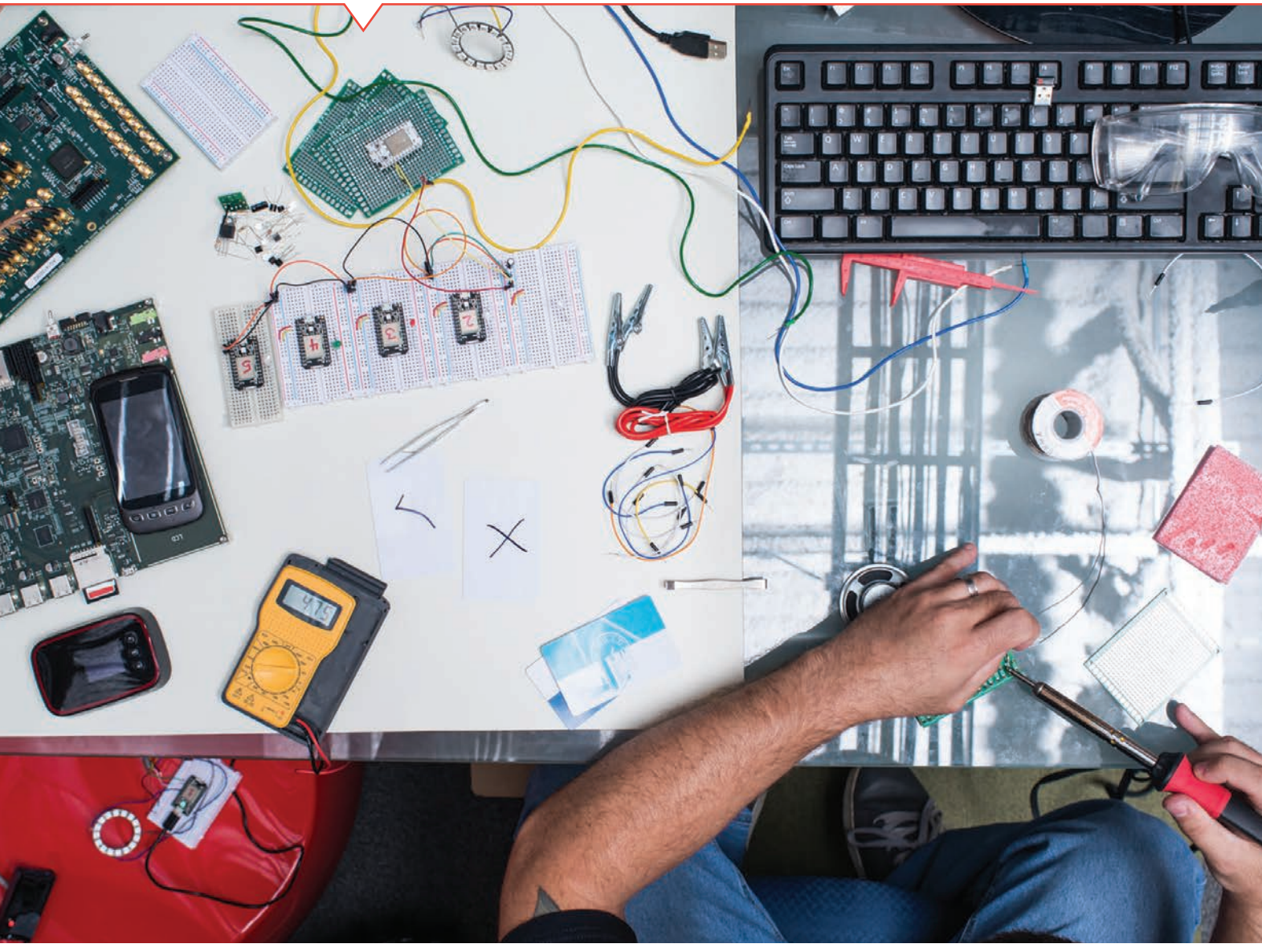

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Upfront

The Blind Community Has High Hopes for Self-Driving Cars

Advocates for the visually impaired are talking to companies and legislators about developing vehicles they will be able to drive independently.

During a few days last August, the parking lot at Perkins School for the Blind, in Watertown, Massachusetts, morphed into a test zone where a golf-cart-like vehicle transported students and staff members, guided by a laptop. It was a prototype from Optimus Ride, a startup in nearby Cambridge that is developing self-driving technologies for electric vehicles.

Though the trip was short and followed a programmed course, it generated excitement at Perkins, the country's oldest school for the blind, which serves 200 blind, visually impaired, and deaf-blind students on its campus and hundreds more through programs in local schools. Advocates for the blind—at Perkins and beyond—say driverless cars could revolutionize their lives, provided the vehicles are designed to be accessible. As the promise of a truly autonomous car draws closer, organizations representing people who are blind are taking a more active role in shaping the vehicles and software being developed. They want companies to make their autonomous vehicles disability friendly rather than producing special cars for the visually impaired, which would probably be extremely expensive.

Dave Power, Perkins's president and CEO, knows the blind community can't assume that autonomous-vehicle makers will take their needs into account, so he invited technology companies to campus to make presentations and gather feedback. "We want to help these vendors build accessibility into their designs and think about people who are blind up front," says Power. Optimus Ride was the first company to respond to his invitation. During its visits, the startup test-drove its vehicle on Perkins's 38-acre property. It also held a brainstorming session to learn how driverless cars can best serve blind people and whether they could be deployed as shuttles on large campuses. Perkins employees say they gave the startup numerous suggestions, such as making sure to provide adequate floor space for service dogs. They also emphasized the need for a nonvisual interface that passengers could use to communicate with the car. For example, a touch-screen-controlled vehicle could accommodate blind users by integrating voice technology or haptic feedback. The setup could mimic the gesture-based screen readers that people with impaired vision use to navigate their smartphones and apps.

Beyond vehicle and software design, the blind community wants to influence regulations governing driverless cars. The American Council of the Blind (ACB), an advocacy group, has been tracking state laws to ensure that they don't prohibit blind people from using autonomous vehicles. When early-adopter states, such as Nevada, were considering legislation on self-driving cars, blind advocacy groups asked lawmakers to keep the wording less specific, according to ACB president Kim Charlson. "We don't think being blind should be a reason why we can't take advantage of these cars," she adds. "On the contrary, we think it's a reason we should use them." *—Elizabeth Woyke*

ANDREA CHRONOPOULOS

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The Complicated Reality Behind Chinese Cyberattacks

Upfront

Making AI Smarter, Faster

Algorithms usually need thousands of examples to learn something. Researchers at Google DeepMind found a way around that.

Most of us can recognize an object after seeing it once or twice. But the algorithms that power computer vision and voice recognition need thousands of examples to understand a new image or word.

Researchers at Google DeepMind now have a way around this. They made a few clever tweaks to a deep-learning algorithm that allows a system to recognize objects in images and other things from a single example—something known as "one-shot learning." The team demonstrated the trick on a large database of tagged images, as well as on handwriting and language.

The best algorithms can recognize things reliably, but their need for data makes building them time-consuming and expensive. An algorithm trained to spot cars on the road, for instance, needs to ingest many thousands of examples to work reliably in a driverless car. Gathering so much data is often impractical—a robot that needs to navigate an unfamiliar home, for instance, can't spend countless hours wandering around learning.

Oriol Vinyals, a research scientist at Google DeepMind, a U.K.-based subsidiary of Alphabet that's focused on artificial intelligence, added a memory component to a deep-learning system—a type of large neural network. Such systems need to see lots of images to fine-tune the connections between their virtual neurons. The team demonstrated the capabilities of the system on a database of labeled photographs called ImageNet. The software still needs to analyze several hundred categories of images, but after that it can learn to recognize new objects from just one picture. It effectively learns to recognize the characteristics in images that make them unique. The algorithm was able to recognize images of dogs with an accuracy close to that of a conventional data-hungry system after seeing just one example.

The algorithm can recognize an image of a dog after seeing one just once.

Vinyals says the work would be especially useful if the system could quickly recognize the meaning of a new word. This could be important for Google's core search engine, since it could enable it to quickly learn the meaning of a search term it hasn't seen before.

Deep-learning systems are becoming more useful, especially with the addition of memory mechanisms. Another group at Google DeepMind recently developed a network with a flexible kind of memory, making it capable of performing simple reasoning tasks—for example, learning how to navigate a subway system after analyzing several much simpler network diagrams.

"I think this is a very interesting approach, providing a novel way of doing one-shot learning on such large-scale data sets," says Sang Wan Lee, who leads the Laboratory for Brain and Machine Intelligence at the Korean Advanced Institute for Science and Technology in Daejeon, South Korea. But others are more skeptical about its usefulness, given how different it still is from human learning. For one thing, says Sam Gershman, an assistant professor in Harvard's Department for Brain Science, humans generally learn by understanding the components that make up an image, which may require some real-world or common-sense knowledge.

According to both Gershman and Wan Lee, it will be some time yet before machines match human learning.

—Will Knight

TO MARKET

Tertill

Gardening robot

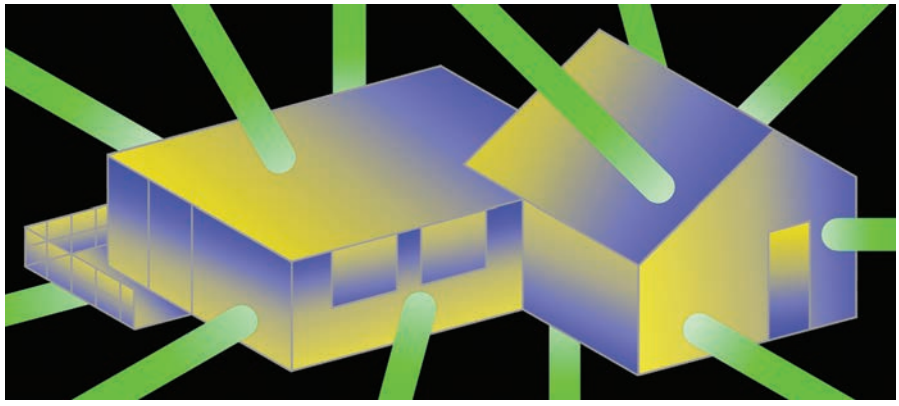
COMPANY:
Franklin Robotics

PRICE:
$250

AVAILABILITY:
Summer 2017

Roboticist Joe Jones wants the Tertill to do for our gardens what the Roomba, the vacuum-cleaning robot he helped create, did for our floors. The solar-powered Tertill operates autonomously, using sensors to identify obstacles and a string trimmer to cut weeds. The prototype is aimed at the casual gardener, but Jones hopes later versions of it will appeal to organic farmers who want to weed their crops without using herbicide. When the Tertill rolls over a plant that is shorter than its one-inch-high bumper, it assumes the plant is a weed and activates the trimmer. It turns away from plants that are taller than its bumper, and from collars that can be installed to protect seedlings. *—Elizabeth Woyke*

COURTESY OF FRANKLIN ROBOTICS



LAURIE ROLLITT

Smart Homes Could Be Cheaper to Insure

Linking doorbells and thermostats to the Internet can cut down on risk.

Insurers such USAA and American Family have lately begun offering to strike a high-tech bargain: wire your home with Internet-connected devices such as a new thermostat, and get a discount on your home insurance policy in return. Offers like that could speed up the adoption of smart gadgets, revamp the insurance business, and transform how we manage our homes. In the future, your insurer might call a plumber before a pipe bursts, for example. But the data needed to help prevent leaks or burglaries will also introduce new risks, such as vulnerabilities to data loss or ransomware.

State Farm offers a discount on your home policy for installing a Canary home security monitor, for example. Liberty Mutual will send you a Nest Protect smoke detector, worth $99, free of charge and cut the cost of fire coverage. Some insurers want to go further. They think that urging us to wire our homes with Internet-connected devices will open up a flood of lucrative new data that can make their existing business of handling claims more efficient while creating a new relationship with the customer. With a feed of data from your home, an insurer could help you prioritize maintenance tasks and fix problems such as leaky pipes before they caused major damage.

Jon-Michael Kowall, assistant vice president of innovation at USAA, says he's aiming to create something like a "check-engine light for the home." For example, an insurer might be able to warn someone with moisture sensors installed that a pipe is likely to fail soon, or even deliver notifications about whether or not a child made it home from school on time.

But insurers' dreams of rewiring how we look after our homes have raised questions about privacy and security. For example, the same data that allows a company to prevent damage from water leaks might also be used to profile some customers as being more likely to engage in risky behavior, and their premiums might quietly be raised. Both American Family and USAA say they communicate clearly with policy holders and make sure that people understand what will be done with their data. *—Stacey Higginbotham*

QUOTED

"The young mice became almost as decrepit as the old ones."

— Irina Conboy, a researcher at UC Berkeley, who discovered that transfusions of blood from old mice made young mice deteriorate.

"Google built the iPhone [of self-driving cars] and we are building Android."

— Sebastian Thrun, CEO of Udacity, which is developing an open-source autonomous-driving software platform.

"People have this idea that because it's a computer it's neutral."

— Christo Wilson, an assistant professor at Northeastern University, on racial and gender bias in algorithms used by two gig-economy platforms, TaskRabbit and Fiverr.

BY THE NUMBERS

0.2 percent

Amount that global gasoline consumption is expected to decrease by 2040, thanks in part to electric cars, according to the International Energy Agency.

100

Number of bitcoins that hackers demanded from the San Francisco Municipal Transportation Agency for a decryption key to get its light-rail ticketing system back online.

20 percent

Growth in size of tobacco plants after scientists used genetic engineering to help boost the efficiency of photosynthesis.

400,000

Estimated number of bots that were tweeting about the U.S. election during a one-month period last fall, according to a study by the University of Southern California.

Upfront


¿Vas solo?
Por eso ya nunca
se ven los volcanes.
#uberPOOL
TAXI
Ford

Uber's Ad-Toting Drones Are Heckling Drivers Stuck in Traffic

Drivers stuck in traffic in Mexico City lately have found themselves being buzzed by a fleet of sign-toting drones. "Driving by yourself?" some scolded in Spanish. "This is why you can never see the volcanoes"—a reference to the smog that often hovers over the mega-city and obscures two nearby peaks. It wasn't exactly a plea for environmentalism, though—it was an ad for the ride-share service UberPool, part of Uber's big push into markets across Latin America. Uber sees Latin American countries as promising targets for expansion, and its strategy, apparently, involves accosting drivers in gridlock with a swarm of drones. *—Michael Reilly*

Photograph by Brett Gundlock

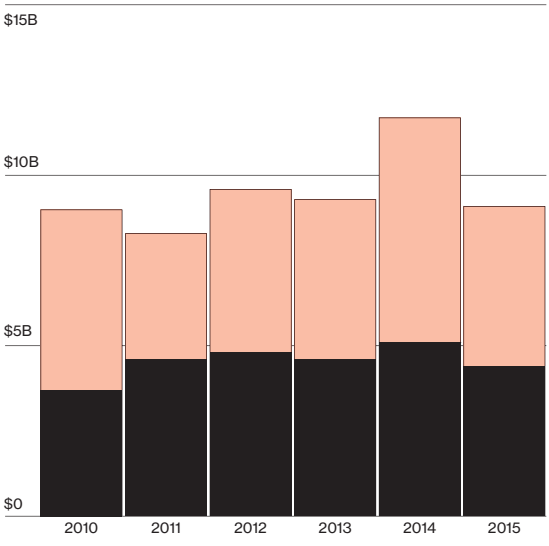
Upfront

Will the Climate Treaty Get the Money It Needs?

Reducing greenhouse-gas emissions to comply with the Paris agreement will require technological breakthroughs, which is why more than 20 countries formed a plan called Mission Innovation. It aims to double research and development in clean energy technologies over the next four years. But if Donald Trump pulls back on the U.S. commitment, the entire plan could crumble.

Global R&D in Renewable Energy

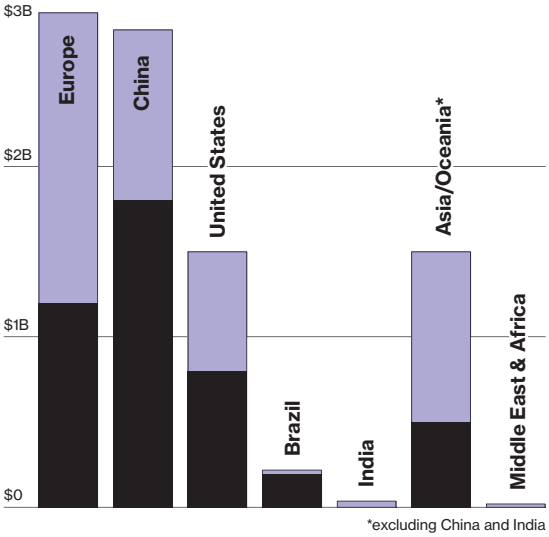
Relatively little research money goes toward renewable energy today. For reference, the world invests around $170 billion annually in life science R&D. ■ Government ■ Corporate



Renewable-Energy R&D by Region in 2015

The biggest emitters also lead the way in research spending.

■ Government ■ Corporate



*excluding China and India

Commitments to Mission Innovation

The United States is due to be the largest source of increased investment in clean energy, including nuclear power and grid technology. The worldwide total could hit nearly $30 billion by 2021—assuming the U.S. stays in.

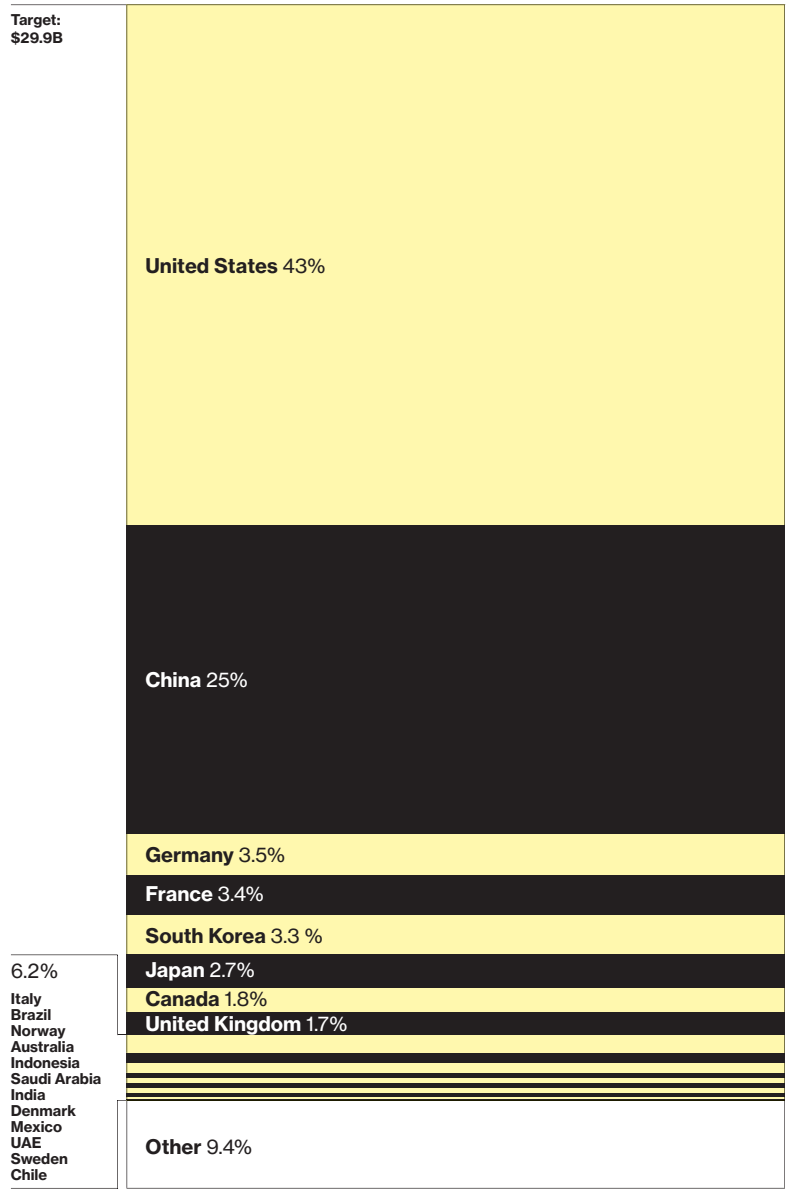


ILLUSTRATION BY LUKE SHUMAN; DATA FROM BLOOMBERG NEW ENERGY FINANCE, UNITED NATIONS ENVIRONMENT PROGRAM, AND MISSION-INNOVATION.NET

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Upfront

Betting on the Blockchain

Twenty years ago, Brian Behlendorf helped kick-start the Web. Now he says the technology behind Bitcoin can make the world fairer.

MARC ASPINALL

Brian Behlendorf knows it's a cliché for veteran technologists like himself to argue that society could be run much better if we just had the right software. "I've been as frustrated as anybody in technology about how broken the world seems," he says. "Corruption or bureaucracy or inefficiency are in some ways technology problems. Couldn't this just be fixed?"

Last summer Behlendorf made a bet that technology can solve some of those apparently human problems. After leaving a comfortable job as a venture capitalist working for billionaire Peter Thiel, an early Facebook investor, he now leads the Hyperledger Project, a nonprofit in San Francisco created to support open-source development of blockchains, a type of database that underpins the digital currency Bitcoin by verifying and recording transactions.

Many governments and large companies are exploring blockchain technology, not because they want to use digital currency—Bitcoin doesn't look likely to become widely used—but as a way to work with other kinds of data. They think blockchains could make things as varied as financial trades, digital health records, and manufacturing supply chains more efficient and powerful.

> **"If we do our job right, you won't ever hear about us. We become plumbing."**

A blockchain stores transactions or other data over time, in a record that can be made effectively indelible using cryptography. And it can be designed to be operated by a group of companies or individuals together in such a way that no single entity controls the system or its data. That is seen as making it possible for companies to work together more easily. The argument goes that they can safely bring their data together on a shared neutral system, instead of keeping it locked away inside private internal systems. A recent survey of financial institutions, the first big industry to jump into researching blockchain technology, suggested that the sector will spend $1 billion on blockchain initiatives this year.

The Hyperledger Project, which exists to accelerate development of the software needed to get blockchains working, has almost 100 corporate backers, including IBM, J.P. Morgan, and Air-

Upfront

bus. Behlendorf says that blockchains will have additional benefits beyond large corporate commerce. He's had frustrating experiences trying to improve government and public infrastructure using technology, and in retrospect, he believes blockchains would have helped. After working on the Obama presidential campaign in 2008, Behlendorf joined a White House initiative to make government more transparent using technology. He later led a project at the Department of Health and Human Services trying to make it easier to move health records around, and he served as chief technology officer for the World Economic Forum.

All these efforts could have used a way to create trustworthy digital infrastructure that doesn't centralize power with one company or authority, he says. The idea that converted him to blockchain technology was using it to record land titles (something Sweden and the Republic of Georgia have considered). He likes that claims written into a blockchain should be quicker to verify and transfer. False ownership claims, or attempts by corrupt officials to manipulate records, should also be easier to detect if many different organizations, or even the public, can inspect that blockchain.

"Even in the most boring of circumstances, these technologies could lead to fairer, more objective outcomes for people up and down the economic stack," he says.

Behlendorf, 43, has a calm, friendly manner, a neat ponytail, and a track record of inventing and incubating technological infrastructure that helps transform society. In 1995 he helped launch the open-source Apache Web server, laying the foundation for the early growth of the World Wide Web. Apache—along with the community of developers Behlendorf nurtured to support it—still powers roughly half of all active websites. He wants Hyperledger's blockchains to be similarly pervasive, if mostly invisible. "If we do our job right, you won't ever hear about us," he says. "We become plumbing."

Hyperledger was founded in late 2015 by the Linux Foundation, which legally and financially supports the open-source operating system Linux, on the premise that infrastructure designed to redefine how organizations interact would be best developed in public. "It needs to be a shared asset rather than a technology controlled by a single vendor," says Chris Ferris, chief technology officer for open technologies at IBM, which was a founding member of the project.

Blockchains make it easier for companies to share data securely.

One reason Behlendorf joined Hyperledger, he says, is that the current moment reminds him of 1995, when Apache was in the works and he had just helped launch the world's first ad-supported website, for *Wired*. If you know where to look, the pieces are there to build something momentous, he says: "There's this sense that there are major new business models and companies that could emerge from this."

Building on his experience shepherding open-source communities, Behlendorf is trying to make Hyperledger into a home for many different blockchain technologies. The project will vet and select the best ideas and offer administrative support, but work on them will rely entirely on companies and individuals to pitch in ideas and code. The most mature plans for using blockchains aim to cut costs for financial institutions in tasks such as settling transactions involving bonds or other financial instruments. "All the back-office stuff can be simpler and more reliable, and they can save a tremendous amount of money," explains David Yermack, a professor of finance at New York University. "Today there are a lot of people working in banks just checking the work of other people."

Behlendorf is happy to be helping those efforts, but he becomes more animated when talking about less conventional uses for financial blockchains. One example is a project—unconnected to Hyperledger—at Kenya's Dadaab refugee camp, where a blockchain is used to help residents establish a financial identity through their dealings with aid agencies. Behlendorf says this shows how the technology could widen access to banking. Hyperledger itself formed a working group last month that will propose projects in health care. Making it easier for patients to move their medical records between providers is one area of interest. The government has spent billions to advance the idea of portable electronic health records. But progress has been slow because organizations see a competitive advantage in keeping patient data siloed.

Companies, researchers, and even the U.S. government are now considering how blockchains could break the deadlock. Behlendorf argues that the technology could create infrastructure that gives patients primary control over their data.

Over the next year, experimentation from Hyperledger and others will start to provide more concrete evidence of whether the technology can deliver disruptive ideas like that, says Chris Curran, chief technologist at PricewaterhouseCoopers, which is working with companies in finance and other sectors interested in blockchains. "We're coming to a moment when we'll find out if this really can reinvent industries," he says. *—Tom Simonite*

Alibaba Group 阿里巴巴集团

ALIBABA TARGETS THE GLOBAL MARKET WITH THE APSARA ALIWARE PLATFORM

The Chinese technology giant has launched a multipurpose platform-as-a-service technology built for scale and reliability—and capable of responding rapidly to changing market and business demands.

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Jingyu Wang, R&D Leader, Cloud Products, Aliware

Lin Zhao, Product Leader, Cloud Products, Aliware

Customers demand more from their e-commerce technology: more information, more say in product design, more service via their preferred channels.

It's no secret: Organizations of all sizes are struggling to build the nimble architectures and secure backbones required for today's digital-business needs and rapid-fire online transactions.

To address this need, Chinese e-commerce and cloud-services powerhouse Alibaba recently debuted its enterprise-class Internet architecture, Apsara Aliware, which uses the underlying technology that powers Alibaba's successful online marketplaces. Offered through Alibaba Cloud, the cloud computing arm of Alibaba Group, Apsara Aliware introduced Alibaba's cloud and middleware expertise to customers who are currently mainly in China, though Alibaba plans to offer the solution globally.

Officially known as the Enterprise-Class Internet Architecture: Apsara Aliware, the solution consists of a proprietary technology stack and a highly agile and scalable cloud platform. It supports all Alibaba Group entities, including Taobao (an online marketplace that resembles eBay), Tmall (like Amazon, a business-to-consumer open platform that allows brands to sell goods and services), and Alibaba.com (a business-to-business platform), as well as Alipay, a service similar to PayPal.

The enterprise-class Internet architecture Apsara Aliware is the cornerstone of the Alibaba Group's technology innovations, supporting a diversified business portfolio that includes business, finance, logistics, cloud computing, video broadcasting, and navigation services. For instance, the Aliware platform processed total sales of more than $17.8 billion in the 2016 Double 11 Global Shopping Festival, up from $14.3 billion in 2015. During the 2016 event, the platform also supported peak volumes of 175,000 transactions and 120,000 payments per second.

The technology's value proposition is simple, says Jiangwei Jiang, Alibaba research staffer and head of the Aliware team: "Aliware helps to enhance corporate IT system responsiveness, leading to huge improvements in enterprise business responsiveness and significant reductions in cost."

Aliware is used by large Chinese companies in manufacturing, sales management, government, telecommunication, and retail. Specific clients include the Chinese petrochemical company Sinopec and Zhejiang Tobacco, among others. According to Data Center Knowledge, an industry news website, the primary cloud user base includes mobile-app developers, system integrators, Internet gaming and online platforms, and e-commerce and Internet finance companies.

A Platform for Efficiency and Innovation

Aliware customers benefit from Alibaba's considerable expertise in building a reliable and hugely scalable digital backbone for online transactions. Few organizations have the experience and resources to develop their own platforms for handling high user and transaction volumes securely and speedily. For that reason, it's less expensive and more efficient for many of them to instead use what Alibaba has already built.

"The essence of the platform is to enhance the efficiency of industry operations, to narrow the gap between the end user and the service or manufacturing enterprise, and to speed up the response to market changes," Jiang says.

Consider, for example, the traditional car-manufacturing paradigm. After producing the cars, manufacturers and car buyers typically are out of touch because the local car dealership sits between the two sides. Through the Aliware platform, car manufacturers can interact directly with end customers, capturing their preferences for future product development as well as car performance and quality information from the field. Data from manufacturing, customer management, supply chain, marketing, and other groups is shared and linked seamlessly.

The Internet and mobile technologies have profoundly changed the way customers and companies interact, says Jingyu Wang, Aliware cloud products R&D leader. Customers demand more from their e-commerce technology: more information, more say in product design, more service via their preferred channels.

"As the production and manufacturing industries accelerate to keep pace with the digital information age, the enterprise demand for data storage and computing capacity will grow far beyond the maximum capacity of the traditional hardware-supported

$17.8 BILLION

Total sales for 2016 Double 11 Global Shopping Festival on Alibaba platforms

mainframe system," Wang says. As a result, Alibaba believes that demand for enterprise-class platform-as-a-service infrastructure will grow as companies seek to acquire infrastructure that is more effective than anything they could build themselves.

Evolution of the Aliware Platform

Alibaba knows more than most companies about what's involved in building such a platform; after all, the company has been in the Internet business since its inception in 1999.

In 2008, Alibaba began to alter the technical architecture underpinning its online retail platform Taobao.com to make it more responsive to changing needs. Back then, the site leveraged commercial databases, minicomputers, and high-end storage. Each business sector had a separate system and a database accessing shared data without a common service layer, an architecture that created three problems: low rates of R&D efficiency, weak system scalability, and limited ability for technical updates.

Alibaba's technical staffers took two steps to fix these problems. First, they established a shared service layer consisting of such service entities as commodity, transaction, marketing, store, recommendation, inventory, logistics, and payment. "The advantage

175,000
2016 Double 11 Global Shopping Festival on Alibaba platforms
TRANSACTIONS PER SECOND

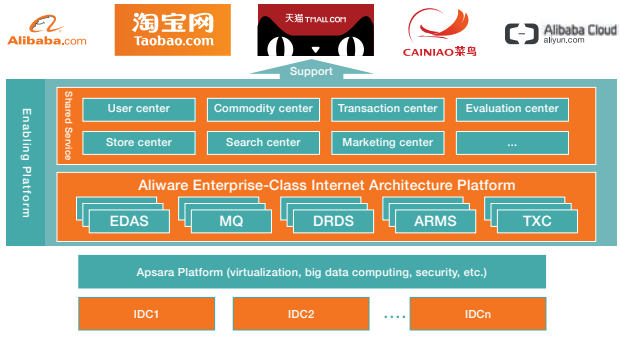
is that it is easy and quick to build a new business requirement from scratch. Meanwhile, any change in data structure only needs to be changed in one place," Jiang says. This concept—since then popularized in the microservices architecture—was a novel approach in 2008.

The second step was the large-scale application of distributed middleware (the predecessor of Aliware). That is, they built a software application architecture layer above the resource layer, developed applications efficiently, seamlessly realized application and terminal communication, and expanded data storage horizontally.

Currently, Aliware, an enterprise-level Internet architecture platform, consists of five major products: EDAS, Enterprise Distributed Application Service; MQ, Message Queue; DRDS, Distributed Relational Database Service; ARMS, Application Real-Time Monitoring Service; and CSB, Cloud Service Bus.

A Rigorous Approach to Testing and Quality Management

Alibaba frequently needs to quickly "stand up" new features on its own platforms. "Oftentimes, we are required to launch one function today and then another totally different function tomorrow," says Lin Zhao, product leader of the Aliware cloud products team. This agility benefits Aliware users, giving them the ability to build up nimble systems and accelerate speed to market, and to achieve rapid business innovation.



With changes occurring constantly, automated quality assurance is paramount. "We have a complete product-requirements management platform, a bug-management platform, and a large number of automated test scripts," Zhao says. Alibaba does regression testing before every new release. For important product features, the technical team performs product-development unit testing with help from professional testers. Test scripts are added to the automatic test platform, ensuring continuous effort to improve product quality.

Aliware: A Versatile Platform for Enterprises and Government Entities

In the Chinese market, Aliware currently focuses on selling to government customers, hospitals, universities, and enterprises in multiple industries.

Consider one particular Aliware user, Sinopec Group's epec.com, China's first e-commerce platform for the petrochemicals sector. In a one-year pilot program before its official launch in April 2016, epec.com recorded total transaction value of roughly $2.1 billion, involving 25,647 suppliers, 1,615 buyers, 93,359 registered users and 153,000 goods.

Alibaba is also targeting small to midsize organizations, which tend to embrace public cloud for its versatility and comparatively lower costs.

"We believe that the future for enterprises involves hybrid-cloud-based services," Wang says. "What customers need most is the ability to fully leverage the advantages brought by a distributed system architecture, thereby being able to deal with fast changing business requirements in an easy-to-manage environment, all while achieving swift business innovation."

120,000
2016 Double 11 Global Shopping Festival on Alibaba platforms
PAYMENTS PER SECOND

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INTL.ALIYUN.COM/

By Stephen S. Hall
Photographs by Jonno Rattman

The Cancer Lottery

In her 30-year battle with breast cancer, Carmen Teixidor thought she had experienced every treatment doctors could hurl at the disease. She had endured multiple bouts of radiation and multiple courses of hormone therapy. She tried chemotherapy once, about 25 years ago, but it diminished the quality of her life so much that she's tried to avoid it ever since. She had multiple surgeries, too, and she developed a dread of the moment when she came out of anesthesia and into consciousness, almost inevitably to hear bad news. That is how she first learned, in the summer of 1985, that after doctors had found a large tumor in her left breast they had felt compelled to perform a mastectomy.

CARMEN TEIXIDOR HAS LIVED WITH CANCER FOR OVER 30 YEARS.

DAVID HYMAN IS AN ONCOLOGIST AT MEMORIAL SLOAN KETTERING CANCER CENTER.

"Absolute terror," she recalls, staring down at the floor of her New York apartment. There's never a good time for a cancer diagnosis, but for Teixidor, it came just as her career as an artist had begun to take off—two of her life-size sculptures had been acquired for the grounds of Rockefeller University, and she had recently completed a mural at Harlem Hospital. A slender woman now in her 70s, graying hair gathered in a youthful ponytail, she has dealt with one recurrence after another, submitting to medical tools from the scalpel to, most recently and perhaps most improbably, the molecule.

Teixidor barely noticed when, in the fall of 2013, her doctors at Memorial Sloan Kettering Cancer Center in New York analyzed a small snippet of her tumor and sequenced the DNA in her cancer cells. They did this, as an increasing number of academic cancer centers are doing, to look for telltale mutations that might drive malignant growth. Certain of these mutations are the targets of a new generation of specially designed drugs.

As it turned out, Teixidor's tumor indeed possessed several medically interesting mutations. But there was a catch: no existing drug was targeted to hers in particular. In the fall of 2013 that wasn't particularly worrisome, because her cancer, despite many recurrences, seemed to be under control. And then everything changed.

"Two years ago," she says, "there was a very bad recurrence." She could feel tumors poking out from the back of her skull. Another tumor took root in her jaw. There were tumors in her neck, and scans revealed more in her bones and pelvis. It was a new, and ominous, phase of the disease that has shadowed her for so long. But when her oncologist at Memorial Sloan Kettering Cancer Center in New York recommended a course of chemotherapy, Teixidor refused. "I got very depressed by the idea that I had to choose between nothing and chemotherapy," she admits.

As Teixidor's cancer had changed, however, so too had the science. One of the mutations in her tumors now matched the target of an experimental drug being tested at Sloan Kettering and elsewhere. Even as an academic debate raged over the value of precision medicine in cancer (one recent scientific critique described it as "the precision oncology illusion"), Teixidor enrolled in the clinical trial, and she began taking the drug in the late summer of 2015. Within weeks, she could feel her tumors regressing—and imaging scans subsequently confirmed that they had.

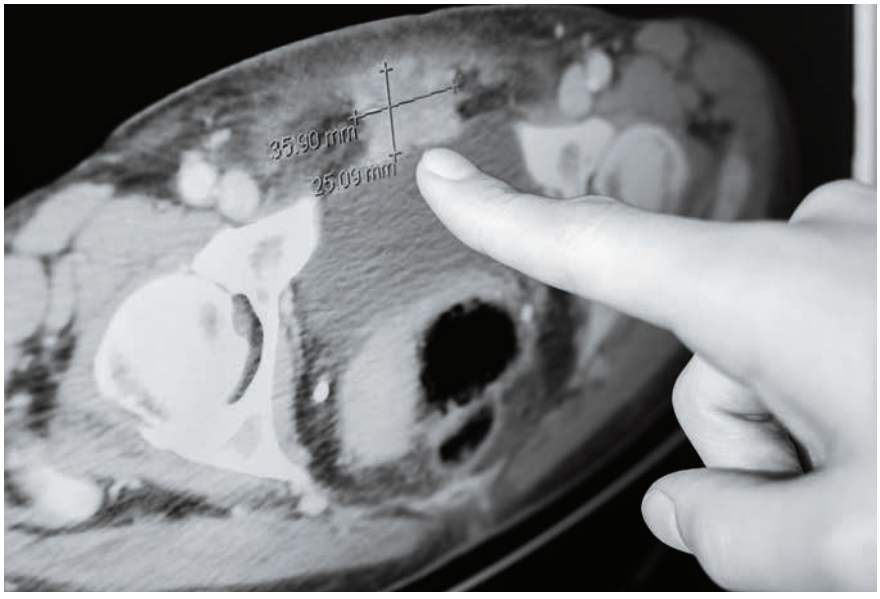
Remarkable though results like hers have been, questions about precision oncology vex doctors, scientists, health insurance companies, and the more than 1.6 million Americans who will receive a cancer diagnosis this year. How many patients might benefit from DNA sequencing of their tumors? Who will have access to this medical approach, which is exceptionally expensive? How much is society willing to pay for the small subset of patients who might benefit?

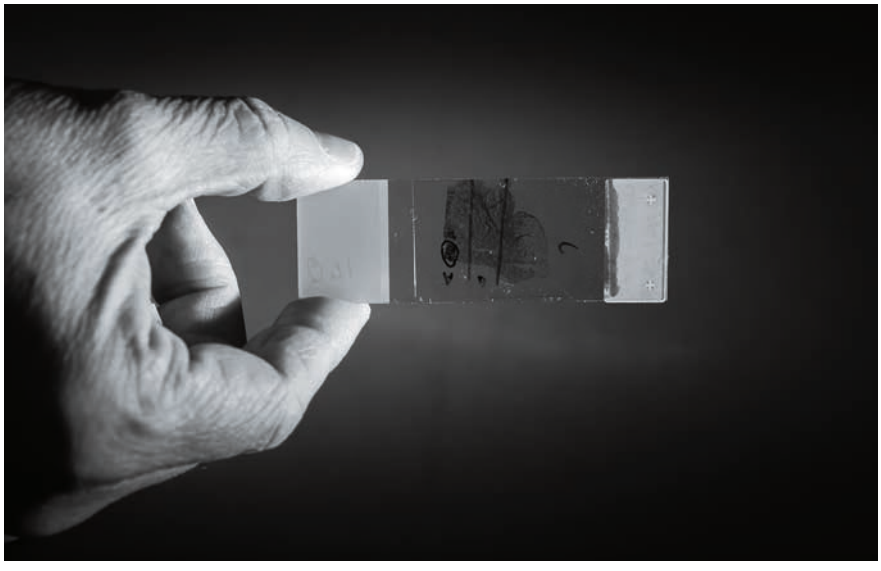
As Teixidor's cancer had changed, so too had the science.

FINDING TARGETS

Ever since the Human Genome Project, scientists have dreamed of using precise, personal molecular information to guide the diagnosis and treatment of human disease. The vision is simple: knowing the DNA sequence of people with particular diseases should reveal the mutations producing those illnesses and offer enticing targets for drugs designed to attack them. Unfortunately, biological complexity still far exceeds medical knowledge. Though researchers hoped that a limited number of common mutations would explain a broad swath of human illness—heart disease, high blood pressure, diabetes, schizophrenia—that has largely failed to hold true.

Cancer treatment is a bright spot in this disappointing story, however. Tumors typically do display genetic aberrations that offer potential targets for drugs. Long before there was widespread talk about precision oncology, targeted therapy had become a major player in cancer clinics. In 1998, the Food and Drug Administration approved a drug for a subset of breast cancer patients whose tumor cells displayed a particularly hyperactive version of a surface molecule known as the HER-2 receptor. Herceptin was the first targeted cancer treatment, and it was joined by two other blockbuster drugs, Gleevec (which targeted a mutation in a form of leukemia) in 2001 and Zelboraf (which targeted a mutation in melanoma) in 2011.





TOP: SLOAN KETTERING'S HYMAN POINTS TO A TUMOR AS SEEN ON AN MRI SCAN.

BOTTOM: A SLIDE CONTAINING DYED CANCEROUS TISSUE FROM A BIOPSY.

The success of these drugs gave rise to the hope that with DNA sequencing becoming relatively cheap and accessible, the genome of any tumor could be mined for clues about how to directly attack its specific mutations. That, in a nutshell, is the animating idea behind precision oncology: doctors could biopsy a tumor, analyze its DNA sequence, and identify mutations—some of which would render the cancer vulnerable to already approved molecular medicines. Where doctors once struggled to treat "breast cancer" or "skin cancer," the mutation, not the tissue of origin, would become the disease's fundamental defining characteristic.

It sounds almost irresistible. But researchers who hoped to find that every cancer has a genetic Achilles' heel have discovered that the biology of cancer mutations is far more complicated. In fact, one of Carmen Teixidor's doctors has been at the forefront of demonstrating just how complicated it is.

BASKET CASE

In April 2012, doctors at 15 leading cancer centers in the U.S. and Europe began enrolling patients in one of the first big clinical trials to test a basic premise of precision medicine in cancer. The study built on knowledge developed over the previous decade showing that half of all patients with melanoma, the deadly skin cancer, possessed a particular genetic alteration in a gene called *BRAF*. This

mutation made melanoma cells vulnerable to Zelboraf. The drug was not a cure, and was not even effective in every patient, but in some patients it temporarily halted the spread of this highly malignant cancer. David Hyman, one of Teixidor's physicians at Sloan Kettering, led an international team of researchers who looked for the same mutation in cancers other than melanoma. They wanted to create a "basket" of patients—individuals who possessed the mutation, regardless of the kind of cancer—and then treat them with the drug.

The results of that study, published in the *New England Journal of Medicine* in August 2015, both encouraged and cautioned the oncology community. Hyman and his colleagues identified patients with the *BRAF* mutation who had lung cancer, colon cancer, thyroid cancer, and other forms of the disease. In some cases, the drug worked; in other cases, somewhat surprisingly, it didn't. In people with non-small-cell lung cancer, for example, more than 40 percent found that the drug slowed the progression of their disease. But in colon cancer patients who possessed the identical mutation, the drug had no effect at all.

The mixed message troubled oncologists like Michael Kolodziej, national director of managed care strategy for Flatiron Health, a data analysis company that is trying to sift messages from electronic health records. "Realistically, for a lot of patients, this is not going to be helpful to them," he says. "For others, it might be the single most important thing you could do. And I can't tell one from the other right now."

Quandaries like this abound. Most of the mutations found in cancers are exceedingly rare, and the medical significance of many of them is murky. Some mutations are treatable; others are not, or at least not yet. Moreover, the treatments have not been uniformly successful. A subset of patients respond, but the responses are typically short-lived; many people do not respond at all.

Researchers are now trying to find out why. Around the same time that Hyman and his colleagues published their results in the summer of 2015, the National Cancer Institute launched a large and ambitious study to rigorously test the idea of matching a specific mutation, in any kind of cancer, with an appropriate targeted therapy. The ongoing study involves 24 different subprotocols, each looking at molecular changes in a specific pathway targeted by the drugs. It involves more than 3,000 patients. NCI arranges for their tumors to be sequenced, and when researchers identify a match—about 22 percent of the time, as of October—it sends the appropriate drug directly to the cancer center treating the patient.

Barbara Conley, at NCI, believes that some of the skepticism about precision oncology is warranted. "I think we will eventually figure it out," she says. "But it's not a slam dunk." Hyman doesn't disagree. But he points out that as more tumors get sequenced, and more targeted drugs are developed and tested, precision oncology is rapidly improving. A patient in the right place at the right time might find that a mutation that is not "therapeutically relevant" one day is treatable the next. And with a tap on his keyboard, Hyman can now find any patient in Sloan Kettering's system who possesses any particular mutation.

"I think we will figure this out. But it's not a slam dunk."

LOTTERY WINNER

In the spring of 2013, Carmen Teixidor had a tumor biopsy, but when researchers at Sloan Kettering looked for common sites of cancer mutations (known as hot spots), the sequencing test didn't work. They repeated the test the following October, and this time the results showed that Teixidor's tumor DNA had several mutations, including one in a gene called *AKT1*. Unfortunately, there was no treatment for it at the time—the mutation was not, in the lingo of precision medicine, "actionable." Like other patients at Sloan Kettering, however, she had her tumor DNA data entered into a database accessible to the lead researcher of any clinical trial at the hospital who planned to test a drug against any of her mutations.

The AKT mutation was first identified as a cause of cancer in 2006, and several drug companies developed AKT inhibitors. Initial trials in the general population of cancer patients were "largely unsuccessful," Hyman says, but matching the drug to patients with the vulnerable mutation might improve the odds of a response. One of the companies working on AKT inhibitors was AstraZeneca, and the company provided an experimental drug called AZD5363 for a clinical trial at Sloan Kettering and elsewhere. When Hyman embarked on the targeted AKT trial in 2014, Carmen Teixidor's name popped up on his computer screen. "With

A LAB TECHNICIAN RETURNS DNA SAMPLES TO A LOW-TEMPERATURE FREEZER AT SLOAN KETTERING.

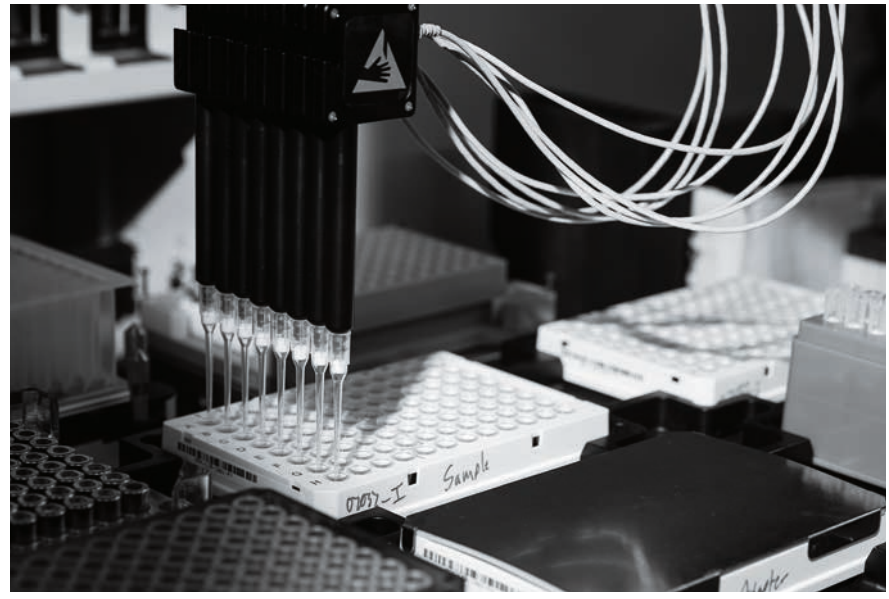
Teixidor's doctors are poring over the DNA sequence for clues.

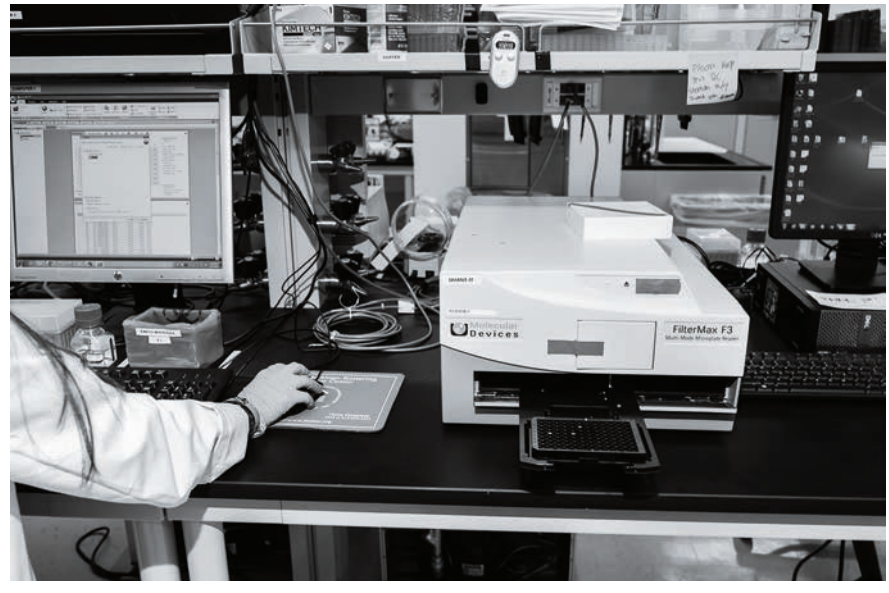
the advance of the field, we kind of caught up with her," Hyman says.

In September of 2015, Teixidor began to take pills that targeted the AKT mutation present in her rapidly spreading cancer. At first, she experienced debilitating side effects, so her doctors adjusted the dose. After that, her response was so swift that the effects were literally palpable. "We had positive results almost immediately," she says. After several weeks of treatment, she recalls, she could no longer feel her tumors: "They disappeared." Hyman adds, "That's pretty typical of what we see when a targeted therapy works. It works very quickly."

Barely two months later, researchers presented preliminary results from the AKT trial at a meeting of the American Association for Cancer Research. The message from the interim analysis, according to Hyman: "The majority of patients have had some degree of tumor regression on this therapy." Teixidor's response, he added, "has been particularly long lasting," and her doctors are now poring over the DNA sequence of her tumor cells for clues to why her cancer has been especially sensitive to the treatment.

On a recent visit to Hyman's group at Sloan Kettering, Teixidor posed a question that few patients had raised about the experimental drug. "I asked about long-term side effects," she said. The answer: no one really knows.





TOP: A ROBOT PREPARES SAMPLES IN A LAB AT SLOAN KETTERING.

BOTTOM: DATABASES AT SLOAN KETTERING MEAN TUMOR INFORMATION IS READILY AVAILABLE.

WORTH IT?

Teixidor was lucky to be treated at a major academic center. Not every cancer center is positioned to take advantage of the latest advances in tumor genomics—an inequity recently acknowledged by officials of President Obama's Cancer Moonshot project. "The vast majority of Americans do not have easy access to precision cancer testing," they noted in a report issued in September, "since oncology clinical trials are offered mainly at large academic cancer centers and not at community cancer centers where most cancer patients receive their treatments."

Indeed, sequencing of tumors remains a relatively uncommon practice. Harold Varmus, a former NIH director and now a professor at Weill Cornell Medical College, says one of the big "lost opportunities" in cancer genomics is how few patients are having it done. Medicare does not cover this type of DNA sequencing, and neither do most health insurers. The cost is not insignificant: tumor sequencing can run from $600 to $1,000 per biopsy, depending on who is doing it. But Varmus points out that it's already cheaper than some standard features of cancer care, such as multiple imaging tests. "These cancer patients end up having *dozens* of imaging scans—CT scans, PET scans, MRIs," he says. Each of those tests typically costs $500 to $5,000.

The cost of sequencing is just part of the reason precision cancer medicine is expensive, however. Targeted therapies can easily cost $10,000 a month. Insurance companies don't always cover them, given the uncertainty over how many patients are likely to benefit.

Vinay Prasad, an oncologist at the Oregon Health and Science University in Portland, recently calculated that only 1.5 percent of patients with recurrent, untreatable solid tumors would be likely to benefit from targeted therapies—which for many would extend their survival by only a few months. Despite the "hype" surrounding rare cases where patients respond dramatically, he wrote in *Nature*, "most people with cancer do not benefit from the precision strategy." Another oncologist, Howard West of the Swedish Cancer Institute in Seattle, questions the way researchers celebrate "the few successes" without "discussing the denominator of all the patients treated in order to achieve those successes." He adds, "Yes, there are a few winners. But it's just like a lottery. Is it worth spending millions of dollars on testing to find the four patients you wouldn't have found otherwise?"

These criticisms mystify researchers like Razelle Kurzrock, of the Moores Cancer Center at the University of California, San Diego. Kurzrock and her colleagues recently analyzed the results from hundreds of clinical trials and argue that when targeted drugs were properly matched to specific tumor mutations, patients exhibited significantly increased response rates and progression-free survival, a measure of the time before a cancer recommences its spread. "Clearly," she says, "there is a large majority of types of cancer that respond."

Her research, first at MD Anderson Cancer Center in Houston and now at UCSD, suggests that patients are already benefiting from next-generation sequencing and matched drugs. "You can get phenomenal responses," she says, adding that response rates have increased even more when doctors use combinations of targeted therapies.

The hope is that once more data is in place, an increasing number of cancer patients will be helped. Hyman cites a genetic alteration that appears in roughly 1 percent of lung cancer patients. Last March, the FDA approved a drug that has "dramatically" extended the lives of these patients, according to Hyman. Not to look for that mutation in the 225,000 Americans diagnosed with lung cancer each year, he says, would be tantamount to rationing health care.

"We can't walk away from this," he says. "Even if it doesn't affect 100 percent of patients, even if it affects 1 percent or 5 percent or 10 percent—that's enough."

Whatever the percentages, Carmen Teixidor has been grateful. On a recent Wednesday afternoon, she sat at her computer, riffling through digital files brimming with her art. One current series of works, she explained, begins with tightly focused, one-inch-square photographs of her own skin; she then changes the initial images—"wrinkles and all"—by mirroring and digitally manipulating them to create stunning fabrics and fantastic three-dimensional shapes such as vases and flowers.

During that conversation, she remarked that living with cancer for so long had been a form of liberation. "What's life," she asked, "if you can't feel its edge?" This past November, however, doctors told her that her cancer had begun to grow again, making her future a little more uncertain. "Right now," she says with a rueful laugh, "I'd prefer not to feel it." ✝

Stephen S. Hall, a science writer based in New York, teaches science communication and journalism at New York University.

TEIXIDOR CONTINUES HER FIGHT WITH CANCER.

Rejuvenating the Chance of Motherhood?

An audacious startup thinks it can give 40-ish women a better shot at having children. Should desperate would-be parents believe it?

By Karen Weintraub

Last April, Omar and Natasha Rajani rented a hall, invited 130 guests, and hired a magician to entertain the little ones. In Natasha's family, first birthday parties are major celebrations. And the Rajanis, who live in Toronto, felt particularly enthusiastic because for a long time they weren't sure they'd ever be able to throw one.

Natasha, 35, struggled for four years to get pregnant. She and Omar, 40, tried naturally at first; then they used hormones, which led to an ectopic pregnancy, in which the fertilized egg implants outside the uterus—usually in the narrow fallopian tube—and must be removed. Then more hormones. Then in vitro fertilization (IVF). Nothing worked.

VIVIENNE FLESHER

Infertility affects more than 10 percent of American women—a number that is rising as many women wait longer before considering parenthood.

Natasha's obstetrician next offered an unusual option: the couple could try a new method meant to improve the odds of IVF, offered by a Boston-area company called OvaScience. The approach, called Augment (for Autologous Germline Mitochondrial Energy Transfer), is so far available only in Canada and Japan (OvaScience hasn't yet sought approval from U.S. regulators). It required the doctor to gather cells from one of Natasha's ovaries and harvest their mitochondria—the tiny power plants that fuel our cells. These extracted mitochondria would then be injected into one of her eggs along with her husband's sperm, and the embryo would be transferred to her uterus during a standard IVF procedure. According to OvaScience, the extra energy from the ovarian mitochondria would give her egg a boost, promoting fertilization.

"What Natasha and I liked about it was it was kind of like self-treatment," says Omar. "We thought that it was something that was safe, and it was almost like the body treating and healing itself. We were very, very excited about the opportunity to try it."

In the round of IVF that Natasha had after trying the new procedure, she got pregnant with a boy, Zain, now almost two. It doesn't really matter, the Rajanis say, whether Augment was the reason for the successful pregnancy. All they know is that it felt like a miracle. They have a toddler with an always-sunny disposition—"He's just an absolute joy of a child," Natasha says—and two more frozen embryos that might one day become his siblings.

Whether Augment actually made the difference in Zain's conception could have far-reaching implications for how we think about both infertility and aging. Infertility affects more than 10 percent of American women—a number that is rising as many women wait longer before considering parenthood. Female fertility starts to decline after age 35. Among women who turn to assisted reproduction techniques such as IVF, only 40 percent of attempts by those under 35 result in a live birth, while 2 percent of those among women over 44 do—largely because of a dwindling number of eggs and a decline in their quality.

Not only could OvaScience's procedure help many women whose fertility has declined with age, but it would be one of the first successful efforts to slow the body's relentlessly ticking clock, providing tantalizing clues for ways to halt aging more generally.

Company cofounder and Harvard University genetics professor David Sinclair says conquering the overall aging process is a matter of when, not if. "We are at a point where we know how to extend life span in mammals, and now there's a race to see who can prove that we can do this in humans," Sinclair says. Female fertility, he says, is one of the first bodily systems to break down with age, and he sees reversing infertility as a gateway to reversing aging itself. The goal, Sinclair proclaims, is "to have revolutionary technologies like OvaScience available to everybody—and not to just treat fertility, but another 2,000 age-related diseases, from diabetes through Alzheimer's."

Despite Sinclair's enthusiasm, it's possible—even likely, some scientists say—that OvaScience's procedure did nothing

at all. For one thing, IVF is notoriously unpredictable. The Rajanis might have just gotten lucky the second time, just as they were unlucky the first.

More than a dozen interviews with experts in fertility and early development reveal little scientific justification for what was done to Natasha Rajani's eggs and those of the 300 other women who have gone through the procedure, which costs an IVF clinic from $6,000 to $7,000. (The fee that clinics charge patients will vary.) The company harvests the mitochondria from what it believes are immature egg cells found in the ovarian lining; the idea is that these so-called egg-precursor cells have fresher mitochondria than the aging mature eggs. But there is little convincing evidence that they are what OvaScience says they are: cells with the power to turn into eggs. And even if such egg-precursor cells exist and their mitochondria are more youthful than those in a woman's eggs, does it prove that such an energy boost can improve fertility?

"There is very little data supporting the benefit of these procedures, and often the biological rationale is incoherent," says Jacob Hanna, an expert in embryonic stem cells at the Weizmann Institute of Science in Israel, who reviewed OvaScience's information at the request of *MIT Technology Review*. "I hope the company can provide solid data and experimentation on these approaches … It sounds more at the moment like voodoo, or alchemy."

So is OvaScience leading a breakthrough in battling one of the most basic processes of aging, or selling false hopes with little scientific justification?

YOUTHFUL MARRIAGE

The founding of OvaScience came about as a marriage of two of medicine's most audacious and often controversial areas: anti-aging research and infertil-

TOP: ZAIN RAJANI ENJOYS HIS FIRST BIRTHDAY CAKE IN APRIL.

BOTTOM: NATASHA AND OMAR RAJANI WERE STRUGGLING WITH INFERTILITY WHEN THEIR DOCTOR SUGGESTED A NEW PROCEDURE.

JANLIL PHOTOGRAPHY

Aging cells have old, slow mitochondria. Hence the idea to rejuvenate eggs with mitochondria from cells that are younger and more energetic.

ity research. The company specifically traces its scientific origins to the work of the reproductive biologist Jonathan Tilly, now at Northeastern University in Boston. Beginning with a 2004 paper, Tilly has been challenging decades of scientific dogma that girls are born with their whole life's supply of "primordial" egg cells, which will eventually mature into eggs. After puberty, this stock of eggs matures at the rate of about one a month, and it never renews. The decline in female fertility around 35 occurs as this supply dries up, and menopause strikes when the eggs run out. But Tilly's research suggested—first in mice and then in people—that the lining of the ovary contains the makings of a new supply. If Tilly is right about his conclusions, solving infertility might be just a matter of finding these egg-precursor cells and triggering them to mature (see 10 Breakthrough Technologies 2012: Egg Stem Cells).

Sinclair says it was natural for him to collaborate with Tilly, who was then at Harvard. Tilly's work touched on subjects that fascinated Sinclair: how the body ages and what might be done to slow that process. "I'd been trying to figure out what are the major reasons we grow old and why don't cells function the older we get," Sinclair says.

Sinclair introduced Tilly to two biotech entrepreneurs, Rich Aldrich and Michelle Dipp, with whom Sinclair had previously run an anti-aging company called Sirtris Pharmaceuticals. That company was based on Sinclair's research into sirtuins, proteins that may slow the aging process and can be activated by resveratrol, a compound found in red wine. Sirtris was sold to GlaxoSmithKline in 2008 for $720 million (GSK closed down its Sirtris facility in 2013, absorbing the sirtuin work into its own research efforts), and the biotech investors were looking for their next big play. When the potential partners asked Tilly how he might commercialize his research, Sinclair says, Tilly came up with the idea of Augment, using the precursor cells to rejuvenate aging eggs. (Tilly declined to comment for this story.) That was enough for the group to create OvaScience, where Dipp served as CEO until last summer.

Sinclair hypothesizes that mitochondria are crucial to aging. The idea is simple. Aging cells have old, slow mitochondria; young mitochondria equal young cells. Hence the Augment program to rejuvenate eggs with mitochondria from cells that are younger and more energetic. Sinclair has also cofounded two other companies, MetroBiotech of Boston and CohBar of Menlo Park, California, to develop drugs related to mitochondrial functions. CohBar hopes peptides made by mitochondria could be useful against diabetes, obesity, and Alzheimer's, among other diseases, while MetroBiotech is pursuing a therapy to treat diseases associated with malfunctioning mitochondria. It is testing a drug that boosts levels of nicotinamide adenine dinucleotide, NAD, a compound involved in energy metabolism in the mitochondria. "The same molecules [in the drug] we think will treat aging itself," Sinclair says, citing a 2013 paper his team published in *Cell*.

Sinclair's interest in aging has become personal. Now 47 and working in a high-stress job at Harvard, he has time to exercise "barely more than once a week." In addition to his academic and commercial duties, he also sits on the advisory board of InsideTracker, a company based

in Cambridge, Massachusetts, that uses levels of glucose, vitamin D, and other blood factors to determine a client's "inner age," as opposed to the chronological one. In 2011, Sinclair says, he clocked in at 57, a decade and a half beyond his actual age. In July 2015, convinced he was going to die young, he upped his daily doses of resveratrol. He also added MetroBiotech's NAD precursor, which has yet to be tested in people and is too expensive for anyone who's not making it to use.

Sinclair says InsideTracker's aging markers now put him at 31. He's lost the weight he'd been carrying since college and has been allowing himself to eat dessert again, because his body can handle it. (Weight loss isn't his goal, he says, but mitochondria are also responsible for burning fat, so weight loss "might be a side effect" of the treatment.) "The results in mice and my single-person experiment indicate that aging is more reversible than we thought," he says.

TOO EARLY

In a pristine lab overlooking a busy highway in the Boston suburbs, OvaScience researchers identify and count what they believe are egg-precursor cells. These constitute, OvaScience says, about 6 percent of the cells on the surface of the ovarian cortex. In the Augment procedure, an IVF surgeon laparoscopically removes a section of this layer about half the size of a dime. The tissue is shipped to an OvaScience lab, where the mitochondria are extracted and shipped back to the fertility clinic. Just before fertilization, the mitochondria are inserted into the egg alongside the sperm. Then IVF proceeds as usual.

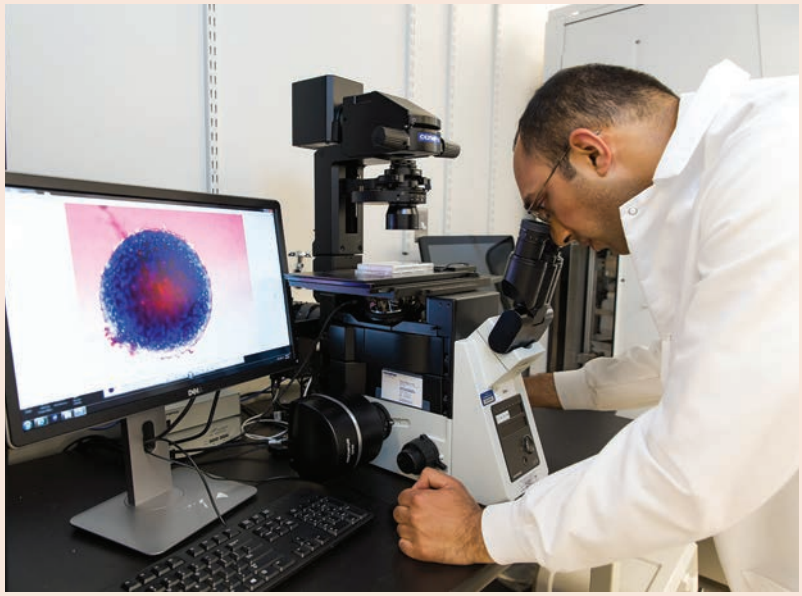
Preliminary data suggests that the procedure improves fertility. In its latest study, released at a conference in November, OvaScience reported a 31 percent success rate among 75 patients who had undergone at least one previous round of IVF before trying Augment. It's notoriously difficult to get good data on fertility clinic results, but in a 2015 study in the *Journal of the American Medical Association*, British researchers found that about 30 percent of women are successful in their first round of IVF and 16 to 25 percent are successful in each subsequent round (without Augment). So if the results for Augment prove to be real, it increases success rates from about 20 percent to 30 percent per round—a significant, if modest, improvement.

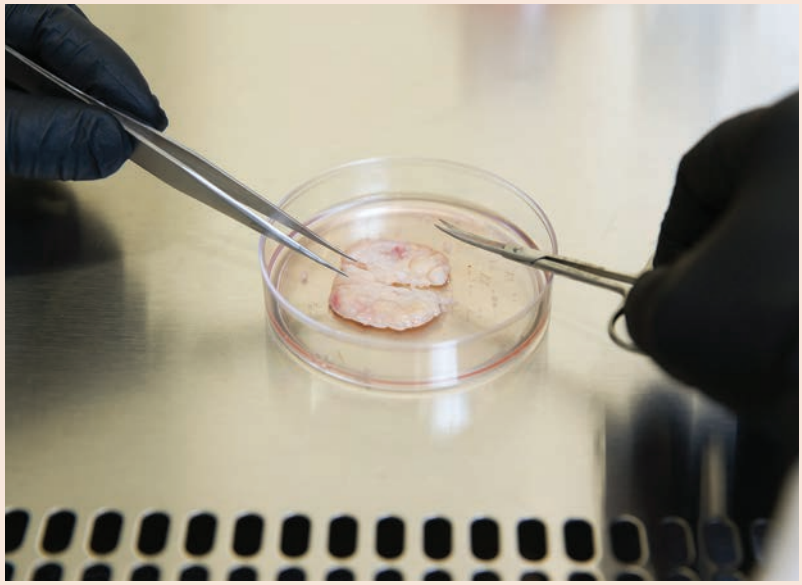
However, those results simply record the experience of Augment patients. As is the case in many early research studies, they were not compared with controls, so there's no convincing evidence that the procedure made the difference. OvaScience's patents on the cells and procedures protect the company's business interests and prevent outsiders from testing its protocol. So there have been no independent tests. I asked one scientist to examine and comment on OvaScience's Augment research. After looking at the material the company had presented to me, he declined to say anything. There wasn't any science to review, he said—just anecdotes.

OvaScience plans two other projects for these egg-precursor cells. In a program it's calling OvaPrime, the cells are extracted from the outer rind of the ovary, isolated, and then reimplanted into the main part of the ovary, where they are projected to mature into healthy, viable eggs. The procedure is designed to help women who don't make enough eggs—about 30 percent of infertile women, according to the Centers for Disease Control and Prevention. The company is doing safety and feasibility trials now and expects to soon decide whether to pursue this approach commercially.

In another program, called OvaTure, OvaScience hopes eventually to perform IVF without hormones. Hormones are now needed to stimulate a woman's body to release as many eggs as possible. But for many women, hormone injections are the worst part of IVF, with the potential to cause mood swings, nausea, vomiting, abdominal pain, and a very small risk of death. With OvaTure, the woman would have some precursor cells removed, and they would be coaxed in a lab dish to mature into fully functional eggs, all without hormones. The company, how-

"What are the major reasons we grow old?"





TOP: A RESEARCHER LOOKS THROUGH A MICROSCOPE AT OVASCIENCE'S HEADQUARTERS IN WALTHAM, MASSACHUSETTS.

BOTTOM: AN OVASCIENCE RESEARCHER DISSECTS A SLICE OF AN OVARY.

ever, is still studying whether this technique will work.

These projects will largely determine just how important OvaScience's contribution to fertility and anti-aging science will be. Augment might have a limited effect even if the precursor egg cells are not truly capable of turning into eggs, as many scientists believe. And Stock says at around $7,000 per treatment, Augment is a good deal if it saves families from another round of IVF, which can easily run $10,000 to $15,000 per cycle. But the two more ambitious efforts, OvaPrime and OvaTure, will never work unless Tilly's conclusions are right. His research was roundly criticized by colleagues in 2004, and his later publications did not erase the skepticism. Mice may very well have these egg-precursor cells, several scientists say. But large, long-lived animals are quite different from mice in terms of reproduction—and Tilly hasn't yet convinced other researchers that women carry around cells capable of extending their fertility.

Still, more scientists are coming around to the possibility that egg-precursor cells exist, says Evelyn Telfer, a reproductive biologist at the University of Edinburgh. Initially quite dubious of Tilly's findings, she changed her mind after touring his lab, welcoming him into her own, and working with the egg-precursor cells herself. "As with all things that are new, it takes time to get into the consciousness of people," says Telfer, who now collaborates with OvaScience. A small study she has recently finished suggests that egg-precursor cells may help women regenerate their egg supply after experiencing a catastrophe, like chemotherapy for cancer. "It's an observation we've made, and we have to do a lot more work to find out what these cells are doing to the ovary and why we're seeing an increased number of eggs," she says.

Regardless of what these cells are, the dozen scientists interviewed—most

OVASCIENCE

of whom didn't want their names associated with the company—questioned the idea of using them to "rejuvenate" older eggs. It's not scientifically obvious that adding extra energy to egg cells would make them more fertile.

Carol Hanna, a staff scientist for the Assisted Reproductive Technology Core Laboratory at the Oregon Health & Science University in Portland, says she and others in the field truly hope that Tilly's science is accurate, but they feel it shouldn't have moved so quickly to commercialization. "I think a lot of people fall in that middle—they want to believe it but haven't seen that one piece of information that convinces them," she says. Renee Reijo Pera, a reproductive and stem-cell biologist at Montana State University, is even more blunt: "Almost everybody thinks that the commercial side of the whole enterprise got way out ahead of the science."

In most areas of medicine other than fertility, it's standard practice to prove that something works before offering it to patients. Regulations in many countries, however, allow fertility clinics to try a procedure first and test it years later. As a result, dozens of so-called add-on procedures to IVF are available to women with very little scientific justification. Industry leaders defend this approach; the first test-tube baby would never have been born if there had been more regulations. But this lack of rigorous oversight also makes patients vulnerable to abuse, says Carl Heneghan, director of the University of Oxford's Centre for Evidence-Based Medicine. "The sheer number of treatments that are available tells you they all can't work," suggests Heneghan. "People will try anything. That's where the problem starts."

But there actually aren't many alternatives available to infertile couples, says Jake Anderson-Bialis, a venture capitalist turned fertility advocate who cofounded the patient community FertilityIQ. International adoptions have become much more difficult; IVF is costly and puts women on a hormonal roller coaster; and buying another woman's eggs if their own are too old can add $30,000 or more to that cost.

Anderson-Bialis says he doesn't blame OvaScience for taking its products to market before the science is firmly established. The infertility business has always been that way. And in his view, the problem of infertility is so big that it justifies some risk-taking.

IMPROVING THE ODDS

This has been a busy few months for OvaScience. In 2016, the company signed on seven new clinics in Canada and Japan, bringing its total to nine worldwide. Harald Stock, who jumped from the board into the CEO's chair in July, says company officials have begun speaking with the U.S. Food and Drug Administration to explore what it would take to bring Augment to the market in the United States. He will soon decide whether to proceed with the OvaPrime and OvaTure programs. And the company, which had more than $130 million in cash as of September 30, decided to move away from its initial business plan of installing small labs in each of the clinics that use its products, instead relying on a centralized lab, which is cheaper and easier for quality control.

Launching a product and a company takes time and personnel, so Stock says he's committed to moving slowly and deliberately. "We need to stay disciplined to not get overwhelmed," he says. "We're still a 100-some-person company and can't be everywhere." The company has chosen to build its business in Canada first, because it can cover most of the country from just a few cities, Stock says, meaning there's no need for a massive sales force. He's waiting to start marketing until enough clinics have been trained, so that anyone who wants Augment can get it.

IVF is a growing business. It's projected to expand from about $10 billion today to $22 billion globally by 2020. Augment, he says, could help women who fail to get pregnant in a first round of IVF. A bigger prize for the company could be in its other projects. OvaPrime could make it possible for women who lack viable eggs to have biological children, he says. And anyone undergoing IVF would prefer to skip the hormones.

In the end, though, OvaScience's market may not turn out to be very big. IVF has been getting markedly better over the last few years. And freezing embryos and even eggs, which costs about the same as IVF plus an annual storage fee of $500 to $1,000, has recently made it much easier for women to preserve high-quality eggs into their late 30s and 40s. It's the age of the egg—not the woman—that seems to matter: women in their 40s fare just as well as younger women if the quality of their frozen eggs is high, says Hal Danzer, cofounder of the Southern California Reproductive Center, a fertility clinic in Beverly Hills, California. Freezing embryos, meanwhile, allows labs to select those that are most likely to succeed, and transfer them after the hormones needed to stimulate egg production have left the body.

Improved IVF success rates leave less room for Augment to shine. Still, boosting the odds even somewhat will entice some prospective parents. Danzer says his patients, many of whom put off parenthood for their careers, are desperate to get pregnant. He has referred several patients to clinics in Canada so they can try Augment, though when asked whether he'd use it in his own clinic, he says: "I think it's a little too early to say."

Karen Weintraub is a freelance health and science writer in Cambridge, Massachusetts.

The Seven Ages of Woman
Hans Baldung Grien

1544

Google's

Long

Strange

Life

Span

Trip

At a laboratory outside San Francisco, money from the founders of Google maintains a large number of naked mole rats. The hairless rodents require exacting, expensive conditions to thrive: they live in coöperative colonies like ants, led by a queen rat. But what is truly extraordinary is that they can live about 30 years—10 times longer than a mouse.

The rodents belong to Calico Labs, short for the California Life Company. In 2013, the cofounder and CEO of Google, Larry Page, announced that his company would form Calico and fund it lavishly to carry out a long-term project, trying to sort out the causes of aging and do something about them. The company's mission: to build a Bell Labs of aging research. It hoped to extend the human life span by coming up with a breakthrough as important, and as useful to humanity, as the transistor has been.

There are reasons to think aging can be slowed in fundamental ways. Among Calico's first hires was Cynthia Kenyon, now its vice president of aging research, who 20 years ago showed that altering a single DNA letter in a laboratory roundworm made it live six weeks instead of three. There is something hair-raising about Kenyon's videos of old, should-be-dead worms wriggling vigorously across a petri dish.

So Google's founders created an academic-biotech hybrid they call an R&D company to follow up on such clues, providing nearly unlimited funding to a group of top researchers. Calico has hired stars like artificial-intelligence specialist Daphne Koller. With equal contributions from Google's parent company, Alphabet, and the drug company AbbVie, it has $1.5 billion in the bank. But despite the hype around its launch—*Time* magazine asked, "Can Google Solve Death?"—Calico has remained a riddle, a super-secretive company that three years in hasn't published anything of note, rebuffs journalists, and asks visiting scientists to sign nondisclosure agreements. In fact, Calico has other researchers "a little miffed," says Felipe Sierra, director of the division of aging biology at the National Institute on Aging. "We want to know what they are doing so we can focus on other things, or collaborate. They are a research company, so what are they researching?"

Calico Labs, the super-secretive anti-aging startup, is going back to basics to try to find the elusive fountain of youth.

By Antonio Regalado

MIT Technology Review has learned that Calico is, in effect, an elite university research group housed within a corporate bunker, doing mostly basic science. It has more than 100 employees and has assembled a Noah's ark of yeast, worms, and more exotic creatures like the naked mole rats, which are kept at the Buck Institute for Research on Aging, about 30 miles from Calico's South San Francisco headquarters.

What's different about a mole rat? That is the sort of costly, open-ended question Calico can afford to ask. And then there's the seven-year study Calico is financing that will follow 1,000 mice from birth to death to search for biomarkers of aging. Right now, there's no proven test for a person's "biological" age; finding one would be scientifically useful and possibly lucrative. "They don't open the kimono much," says Brian Kennedy, a Buck Institute scientist who interacts with Calico. "I think they believe we need a broader grasp on the biology of aging. They recognize it can't possibly be simple."

The Google founders aren't the first billionaires to decide that aging is the "most fundamental unsolved problem in biology," as Calico's press releases put it. Larry Ellison, the cofounder of Oracle, gave away $335 million to scientists studying aging before redirecting his foundation's grants toward eliminating polio in 2013. The investor Peter Thiel has also donated to the anti-aging cause, and there's even a $500,000 Palo Alto Longevity Prize to anyone who can radically extend the life of a mammal.

The Fountain of Youth
Lucas Cranach the Elder

1546

Aging is the inexorable journey from birth to old age and death. Today, some researchers think the aging process could be slowed. The artworks that accompany this story depict the phases of life and the dream of eternal youth.

The difficulty is that scientists don't know enough about why animals age. Calico's Hal Barron, hired from Roche to lead its drug development efforts, told the National Academy of Medicine in 2015 that there would be no short-term payoff. "We believe you have to take a very long view," he said, "and not rush into the clinic until you really know what you are doing."

A hundred and seventy five years ago most people died from infections, not from old age. Thanks to vaccines, better nutrition, and all-around improvements in public health and medicine, life expectancy at birth in wealthy nations has doubled from 40 to around 80 years, an average gain of 2.5 years per decade. But now that we live longer, we have traded up to a new set of killers that are harder to beat: cancer, heart disease, stroke, and dementia.

For all these diseases, aging is the single biggest risk factor. An 80-year-old is 40 times as likely to die from cancer as someone middle-aged. The risk for Alzheimer's rises by 600 times. But what if it were possible to postpone all these deaths by treating aging itself? "I think we have failed in our effort to attack chronic disease when we attack them one by one," Sierra says. "And the reason is that they have one major risk factor, which is the biology of aging."

Overarching theory

David Botstein is Calico's chief scientific officer. He is 74, with a grizzled shadow of beard reaching up from his collar. In

November, I found him at a lecture hall at MIT, where he offered a rare window onto experiments under way at Calico. Botstein, a well-known Princeton geneticist whom Calico recruited out of near retirement, was in town to celebrate the birthday of a successful former student, now a sexagenarian. "The pleasure is coming to see old friends," he says. "The not-so-pleasure is if these guys are 60, what am I?"

In his lecture, Botstein described several technologies—four, in fact—that Calico has for isolating old yeast cells from the daughter cells that bud off them. (One project has the institutional-sounding name Mother Enrichment Program.) These old cells are tracked and subjected to a comprehensive analysis of which genes are turned up or turned down, a technique that is Botstein's specialty.

Botstein told me Calico is exactly what Google intended: a Bell Labs working on fundamental questions, with the best people, the best technology, and the most money. "Instead of ideas chasing the money, they have given us a very handsome sum of money and want us to do something about the fact that we know so little about aging," says Botstein. "It's a hard problem; it's an unmet need; it is exactly what Larry Page thinks it is. It's something to which no one is really in a position to pay enough attention, until maybe us."

Botstein says no one is going to live forever—that would be *perpetuum mobile*, or perpetual motion, which defies the laws of thermodynamics. But he says Kenyon's experiments on worms are a "perfectly good" example of the life span's malleability. So is the fact that rats fed near-starvation diets can live as much as 45 percent longer. The studies Botstein described in yeast cells concerned a fundamental trade-off that cells make. In good times, with lots of food, they grow fast. Under stresses like heat, starvation, or aging, they hunker down to survive,

The Ages and Death
Harmony (The Three Graces)
Hans Baldung Grien

1541–1544

grow slowly, and often live longer than normal. "Shields down or shields up," as Botstein puts it.

Such trade-offs are handled through biochemical pathways that respond to nutrients; one is called TOR, and another involves insulin. These pathways have already been well explored by other scientists, but Calico is revisiting them using the newest technology. "A lot of our effort is in trying to verify or falsify some of the theories," Botstein says, adding that he thinks much of the science on aging so far is best consumed "with a dose of sodium chloride." Some molecules touted as youth elixirs that can act through such pathways—like resveratrol, a compound in red wine—never lived up to their early hype.

According to Botstein, aging research is still seeking a truly big insight. Imagine, he says, doctors fighting infections without knowing what a virus is. Or think back to cancer research in the 1960s. There were plenty of theories then. But it was the discovery of oncogenes—specific genes able to turn cells cancerous—that provided scientists with their first real understanding of what causes tumors. "What we are looking for, I think above everything else, is to be able to contribute to a transformation like that," he says. "We'd like to find ways for people to have a longer and healthier life. But by how much, and how—well, I don't know."

Botstein says a "best case" scenario is that Calico will have something profound to offer the world in 10 years. That time line explains why the company declines media interviews. "There will be nothing to say for a very long time, except for some incremental scientific things. That is the problem."

To get there, Calico is ratcheting up its expertise and skills. Botstein says it has demonstrated it could decode a human genome from scratch, without peeking at the official genome map. That's a difficult task requiring significant investment in computing and know-how. But Calico got the right answer, so it's confident of accurately mapping the genome of the naked mole rat—a job he says is half done. And a precise understanding of how the mole rat's genes are organized may hold clues to its long life. "A lot of what we do is technology development," says Botstein. "It's not interesting, and it's not supposed to be interesting. It's how you put one foot in front of the other so you don't trip on yourself."

"We'd like to find ways for people to have a longer and healthier life. But by how much, and how—well, I don't know."

Big disappointment

To some, Calico's heavy bet on basic biology is a wrong turn. The company is "my biggest disappointment right now," says Aubrey de Grey, an influential proponent of attempts to intervene in the aging process and chief science officer of the SENS Research Foundation, a charity an hour's drive from Calico that promotes rejuvenation technology. It is being driven, he complains, "by the assumption that we still do not understand aging well enough to have a chance to develop therapies."

Indeed, some competitors are far more aggressive in pursuing interventions than Calico is. "They are very committed to these fundamental mechanisms, and bless them for doing that. But we are committed to putting drugs into the clinic and we might do it first," says Nathaniel David, president and cofounder of Unity Biotechnology. This year, Jeff Bezos joined investors who put $127 million behind Unity, a startup in San Francisco that's developing drugs to zap older, "senescent" cells that have stopped dividing. These cells are suspected of releasing cocktails of unhelpful old-age signals, and by killing them, Unity's drugs could act to rejuvenate tissues. The company plans to start with a modestly ambitious test in arthritic knees. De Grey's SENS Foundation, for its part, has funded Oisin Biotechnologies, a startup aiming to rid bodies of senescent cells using gene therapy.

Other scientists say it is time to begin large human studies of "geroprotectors"—drugs that could decelerate aging altogether. One such effort is being spearheaded by gerontologists at Albert Einstein College of Medicine, in New York. The medication they hope to test, metformin, is used to treat diabetes. It cropped up as an anti-aging prospect after scientists reviewing medical records found that people taking it not only were much less likely to die than other diabetics but died at a 15 percent lower rate than all other patients.

Metformin lowers blood sugar levels, one clue it may have something in common with a low-calorie diet. But getting a study off the ground hasn't been easy. To convince the U.S. Food and Drug Administration to approve the trial, doctors decided to measure metformin's effectiveness in preventing three separate diseases: heart attack, dementia, and cancer. "They do not recognize aging as a disease, so what we have done is choose diseases of aging with minimal overlap in their causes," says Steven Austad, a biologist at the University of Alabama at Birmingham and scientific director of the American Federation for Aging Research, which has endorsed the metformin study. "If it simultaneously delays them, that would indicate a slowed rate of aging."

The trial is designed to involve 6,000 people and would last six years. It would be the first large study of a geroprotector in volunteers, according to S. Jay Olshansky, a public health researcher at the University of Illinois at Chicago. He therefore rates the trial as significant no matter whether it flops or, as he hopes, sets off "the most groundbreaking events in public health in this century."

The only problem is who will pay for the trial, expected to cost $65 million. The chance the NIH will pay for the entire study is "remote," says Austad, and since metformin is an old drug not covered by patents, drug companies aren't interested either. Instead, Olshansky and Austad are going with what's become a favorite play in research on aging: they plan to hit up billionaires for the money. Funding a groundbreaking advance, Olshansky promises potential investors, could be their "ticket to immortality."

> "There are a lot of charlatans in aging research. I should be careful in what I say, but it attracts pretty quirky people."

Playing the long game

The science of aging is easy to disregard, given its long historical connection to alchemy, quacks, and vitamin pushers. Even now, many scientists do their utmost to avoid the phrase "anti-aging research"—sounding as it does like a promise made on a tin of skin cream. "There are a lot of charlatans in aging research. I should be careful in what I say, but it attracts pretty quirky people," says Gary Churchill, a mouse geneticist at the Jackson Laboratory, in Bar Harbor, Maine.

It can't help, either, that the people who bankroll this science keep saying they hope to live forever. Bill Maris, the former head of Google Ventures who hatched the idea for Calico, has said he thinks it is possible people could live "for 500 years." That's pretty unlikely. In that sense, Calico's creation of a strictly controlled research fortress staffed by recognized leaders makes sense as an inoculum against hokum, maybe even from the people paying the bills. "They are playing the long game," Churchill says. "It's a good strategy. It could leave them positioned a decade from now to have something."

Churchill's work with Calico gives some idea of how long it could take. In April 2016, the company agreed to pay for a large experiment at Jackson Labs to search for a "biomarker" of aging—a molecule, which they hope to find in the blood, whose quantity or properties change with "biological" age, not just with the hands on the clock. Such a diagnostic could be extraordinarily useful, and profitable.

But searching for such a marker is not cheap. At Jackson Labs, Churchill's

team plans to follow 1,000 mice, drawing blood and placing them inside special cages where food and water intake can be precisely measured and the rodents' droppings and urine collected. Half the mice will be on a calorie-restricted diet to extend their lives—necessary to confirm whether a biomarker really tags them as biologically younger. The experiment will generate millions of readings—for levels of growth hormones and glucose, among other things. Churchill wouldn't say how much Calico is paying, but simply feeding that many mice could cost $3 million. "We've mapped it out, planned it. It's immense, and we'd never be able to do this with the NIH," he says. "The willingness to invest in the long term is the most appealing thing about Calico."

Churchill says the ideal biomarker of aging would actually estimate how much longer you have left to live, barring any unforeseen events. And the readout would change if you took a drug or adopted a diet that somehow rescheduled your appointment with the Grim Reaper. With a test like that, companies could see whether their drugs actually influenced aging without waiting many, many years for the answer. Finding such a blood marker would be the kind of breakthrough that aging research so desperately needs—and that Calico was created to discover.

Antonio Regalado is MIT Technology Review*'s senior editor covering biomedicine.*

Le Néophyte
Gustave Doré
circa 1880–1883

HOTTER DAYS WILL DRIVE GLOBAL INEQUALITY

Rising temperatures due to climate change will strongly affect economic growth around the world, making some countries richer and some poorer.

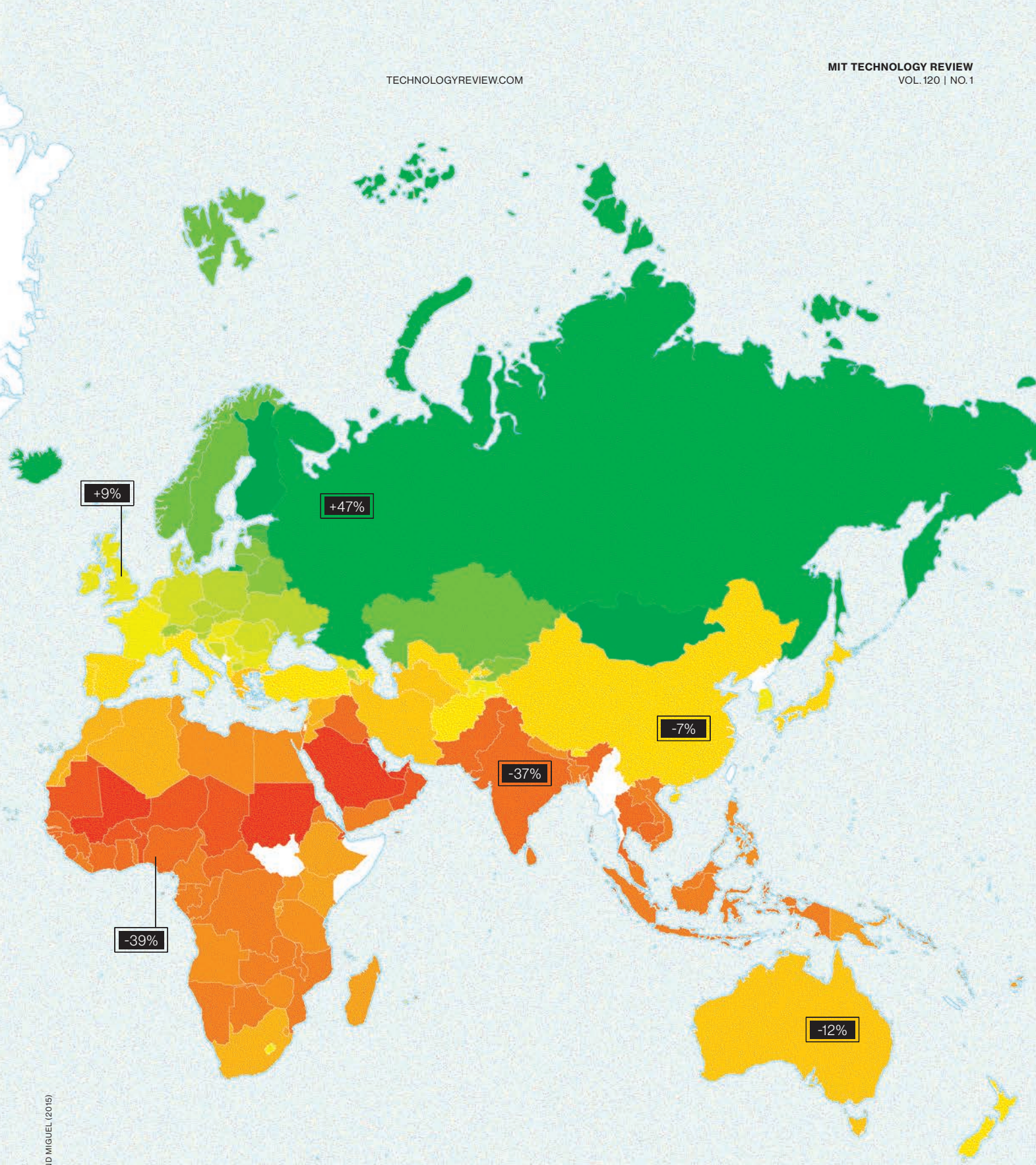
LUKE SHUMAN

Extreme heat, it turns out, is very bad for the economy. Crops fail. People work less, and are less productive when they do work.

That's why an increase in extremely hot days is one of the more worrisome prospects of climate change. To predict just how various countries might suffer or benefit, a team of scientists at Stanford and the University of California, Berkeley, have turned to historical records of how temperature affects key aspects of the economy. When they use this data to estimate how various countries will fare with a warming planet, the news isn't good.

The average global income is predicted to be 23 percent less by the end of the century than it would be without climate change. But the effects of a hotter world will be shared very unevenly, with a number of northern countries, including Russia and much of Europe, benefiting from the rising temperatures. The uneven impact of the warming "could mean a massive restructuring of the global economy," says Solomon Hsiang, a professor at the Goldman School of Public Policy at Berkeley, one of the reseachers who has painstakingly documented the historical impact of temperature. Even by 2050 (see map), the variation in the economic fates of countries is striking.

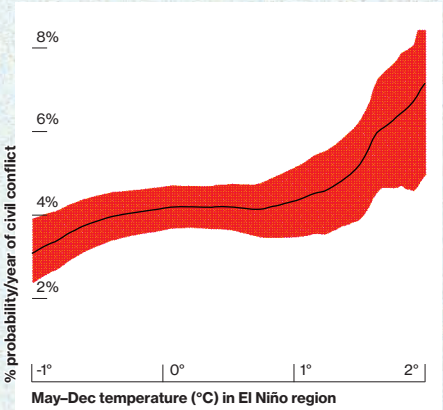
Because poorer countries, including those in much of South America and Africa, already tend to be far hotter than what's ideal for economic growth, the effect of rising temperatures will be particularly damaging to them. Average income for the world's poorest 60 percent of people by century's end will be 70 percent



Change in gross domestic product per capita in 2050 relative to a world without global warming.

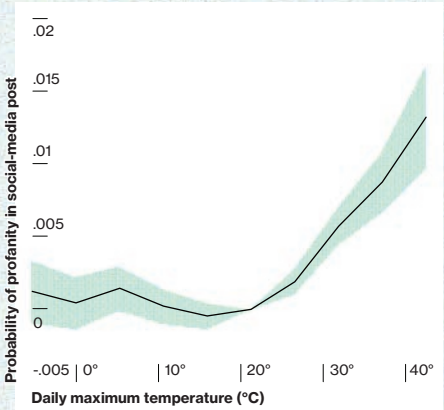
BURKE, HSIANG, AND MIGUEL (2015)

Hot Tempers, Poor Yields, and Sluggish Economies



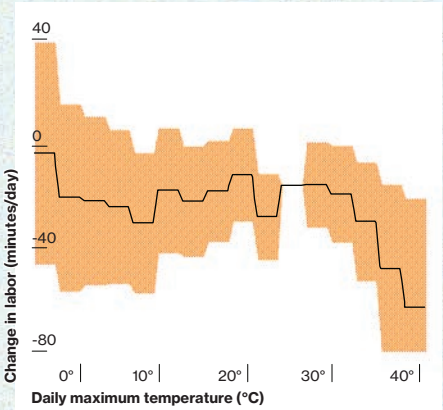
Risk of Civil Conflict

The probability of civil conflict in tropical areas increases in hotter El Niño years relative to La Niña years, according to one study. (Hsiang et al., 2011)



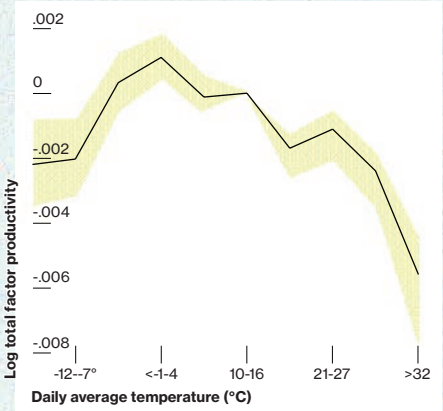
Profanity in Social Media

Study of more than a billion tweets shows rise in profanity as temperatures exceed about 20 °C, suggesting how heat might affect social interactions. (Baylis, 2015)



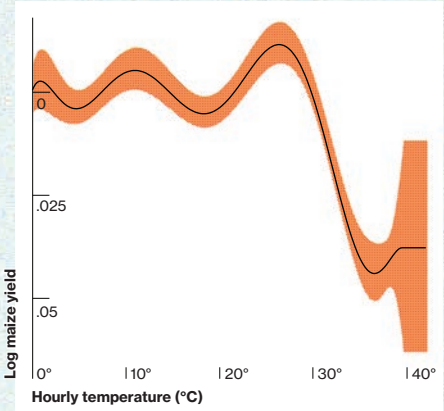
Labor Supply (U.S.)

In "climate-exposed" industries, the amount of time spent working drops off sharply above 30 °C. (Graff Zivin and Neidell, 2014)



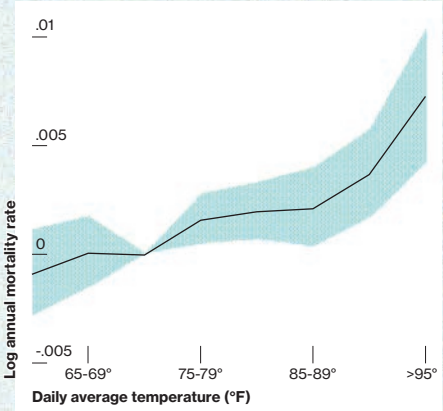
Total Factor Productivity (China)

A key measure of economic productivity shows sharp declines in hot weather. Similar studies of income per capita in the U.S. show a decline at high temperatures. (Zhang et al., 2016)



Maize Yields (U.S.)

Study finds that yields of corn increase until temperatures reach 30 °C, at which point they decline sharply. Similar results were found for cotton and soybeans. (Schlenker and Roberts, 2009)



Mortality (India)

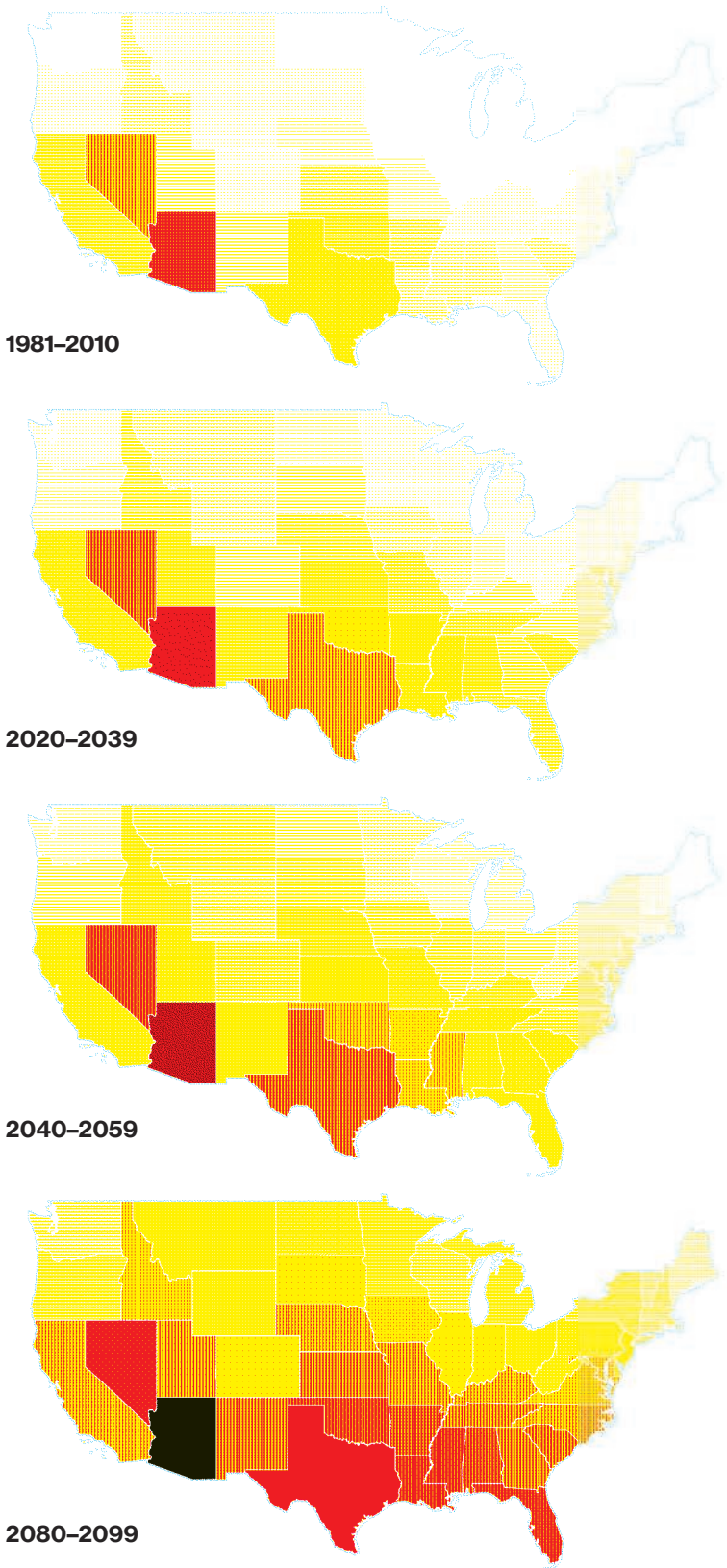
Research shows elevated rate of deaths in India during hot weather. The increased mortality was uneven, disproportionately affecting people living in rural areas. (Burgess et al., 2013)

below what it would have been without climate change, conclude Hsiang and his coauthors in a recent *Nature* paper. The result of the rising temperatures, he says, "will be a huge redistribution of wealth from the global poor to the wealthy."

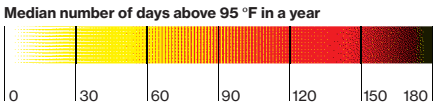
Hotter weather is just one of the effects of climate change; shifts in rainfall and an increase in severe weather like hurricanes are among the others. But by analyzing temperatures alone, Hsiang and his coworkers have provided more precise estimates of how climate change could affect the economy. It turns out, Hsiang says, that temperature has a surprisingly consistent effect on different economic inputs: labor supply, labor productivity, and crop yields all drop off dramatically between 20 °C and 30 °C. "Whether you're looking at crops or people, hot days are bad," he says. "Even in the richest and most technologically advanced nation in the world, you will see [the negative effects]," he says, citing data showing that a day over 30 °C in an average U.S. county costs each resident $20 in unearned income. "It's real money."

Of course, the idea that hot temperatures affect agriculture and the way we work and feel is not new. Indeed, Hsiang points to studies done in the early 20th century on the optimum temperatures for factory workers and soldiers. But he and his colleagues have quantified how changes in temperature alter overall economic productivity for entire countries.

CARLETON AND HSIANG, SCIENCE (2016)



Extreme Hot Days
The number of days above 95 °F (35 °C) will rise dramatically in many parts of the United States if climate change continues unabated.



Hsiang and his coworkers examined both the annual economic performance in each country and the average yearly temperatures from 1960 to 2010. Then they used advanced statistical techniques to isolate temperature effects from other variables, such as changes in policies and financial cycles. Such analysis, he says, is possible because much more historical data is available, and computational power has increased enough to handle it. Then, by using climate models to project future temperatures, the researchers were able to estimate economic growth over the rest of the century if these historical patterns hold true.

Hsiang has also looked at how hot temperatures affect social behaviors and health, concluding that they increase violence and mortality (see charts, opposite page.) What he calls his "obsession" with the social effects of temperature can be traced to his training in the physical sciences. Temperature plays an essential and obvious role in chemistry and physics, but its effects on society and human behavior have been less appreciated. And yet, as his recent work has confirmed, the climate "is fundamental to our economy," says Hsiang. Now he's hoping to provide new understanding of just how an increasingly hot world will affect our future prosperity. *—David Rotman*

In 2006, Raj Shah was an F16 pilot in the U.S. Air Force, flying combat missions in Operation Iraqi Freedom. It was the war's worst year, and Shah had a problem. The display screen in his cockpit had no moving map. The GPS showed him ground coördinates, but there was no overlaid image—no moving dot or icon—that showed where *he* was in relation to those

Procuring Innovation

The U.S. Department of Defense founded a kind of startup in Silicon Valley to accelerate the development and acquisition of new technologies useful to the military. But will it survive President Trump?

MIT TECHNOLOGY REVIEW
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coördinates. "There were times," he recalls, "when I didn't know whether I was over Iraq or Iran." During home leave, he bought an iPAQ, one of the early pocket PCs, and loaded it with a standard, cheap aviation-map program. Back in his F16, he strapped the pad to his lap and relied on it—not the plane's multimillion-dollar mil-spec software—for navigation.

By Fred Kaplan

Shah realized that commercial technology was racing ahead of the U.S. military's own, and that this was a dangerous trend for America's security, given the nation's reliance on its technical edge to win wars.

Today Shah is managing partner of DIUx, the Defense Innovation Unit Experimental, which was created less than two years ago to address this problem. The program's budget is only $30 million, barely the size of a counting error in the Pentagon's ledgers. Yet it's already having an impact, mending the tattered ties between the military and Silicon Valley—and it might revolutionize the way defense contracts are awarded, making U.S. military missions far more likely to take advantage of high-tech inventions.

For the same reason, it's also in the crosshairs of various factions within the Department of Defense bureaucracy and the corporations that supply the military. They have developed elaborate ways of doing business with each other and regard anything deemed "innovative" or "experimental" with suspicion. Yet Shah is convinced that if something like DIUx had started up a few decades ago, his F16 would have had Google Maps built into its display screen.

From the top

DIUx is the brainchild of Secretary of Defense Ash Carter, a theoretical physicist who has taught and done research at Harvard and MIT and previously served in senior posts in the Pentagon. "The concept of a DoD outpost in Silicon Valley, and in other technology centers around the country, was in my mind when I entered office," Carter says. In 2000, he wrote a paper called "Keeping the Technological Edge," foreseeing that commercial industries would soon overtake defense labs at innovation and that, to protect U.S. global interests, the Defense Department would need to form new relationships with the private sector. When Carter took over the Pentagon in February 2015, he was smacked by international crises, but he declared that defending America's strategic dominance in technology was a top priority. Two months into his tenure, he announced the formation of DIUx in a speech at Stanford: the first time a defense secretary had come to Silicon Valley in 20 years. The program was launched in August of that year.

The program's headquarters is located in Mountain View, California, on the grounds of a sprawling Air Force and NASA research base, much of it now occupied by Google. The DIUx staff of around 40 people—a mix of civilians, military, and contractors—work on the second floor of a squat brick office building once used by the Air National Guard, until the area's housing became too expensive for Guard personnel. The corridors are old-school drab, the doors secured with combination locks. But inside, the newcomers have revamped the spaces with blackboards, whiteboards, and desks arrayed in random diagonals, to match the nonhierarchical vibe of a Valley startup.

It was vital, in Carter's mind, to place the office in the heart of Silicon Valley. He wanted to tap into projects that were already in the works—at startups and companies that didn't do business with the government—and adapt them to national-security missions. The budgetary advantages were straightforward: the Defense Department wouldn't have to pay for R&D, because the companies would already have incurred the costs. And DIUx wouldn't pay procurement costs: those would be paid by the military service that agreed to put the product in the field.

But in its first year, despite support from the top, the program seemed doomed. Carter didn't fully appreciate that such an unconventional program had to be run in an unconventional way. He named as DIUx director George Duchak, who'd been a DARPA program manager, director of the Air Force Research Laboratory's Information Directorate in Rome, New York, and a high-tech entrepreneur. But on the organizational chart, Duchak reported to the undersecretary of defense for acquisition, technology, and logistics. Carter had held that post before his ascension to secretary, but it was now occupied by Frank Kendall, an engineer who had worked for big defense contractors. Kendall didn't share Carter's enthusiasm for the whole idea of DIUx and shuffled its oversight to an acting assistant secretary of defense for

DIUx is already having an impact, mending the tattered ties between the military and Silicon Valley.

ILLUSTRATIONS BY JOOST SWARTE

research and engineering, who didn't know what to do with it and wouldn't have had the authority to do much if he did. Duchak was thus three layers away from Carter.

Isaac Taylor saw the ensuing train wreck up close. Taylor had spent the previous 13 years at Google, designing and building its first self-driving cars. From there, he rose to operations director of Google X, where he started a number of projects involving robotics and augmented reality. Still, he was looking for a change, keen to work on "meaty projects that matter to the nation."

Taylor began pitching products from within Google. He soon realized the program couldn't work—not as it was organized. From the sidelines, Taylor also witnessed how two of California's most creative companies came afoul of DIUx's processes. One, Shield AI in San Diego, had built a small, autonomous indoor drone, which the program thought might appeal to the Special Operations Command, whose soldiers might want to know who is lurking inside a building or a cave. The other, Bromium in Cupertino, had designed cybersecurity software that could isolate operating systems from untrusted users. Meetings were held; the interest was palpable. But nothing happened. In Silicon Valley's culture, meetings end either with a decision on whether a deal is possible or, often, with the deal itself. In the Pentagon's culture, meetings lead to more meetings, which might lead to an R&D contract in 18 months, followed by testing, approval, then a renewed competition for a contract to build a prototype in another couple of years, then an assessment, followed by several more stages. No one in the Valley could put up with such delay: among other things, the technology would have changed three times between the moments when the contract was signed and the hardware fielded.

SUSAN WALSH / ASSOCIATED PRESS

ASH CARTER
DIUx is the brainchild of the secretary of defense. He thought it vital to place DIUx in the heart of Silicon Valley: he wanted to tap into projects at startups.

One of Secretary Carter's assistants called Taylor to ask what had gone wrong. Taylor replied that the people at DIUx were talented, but the process doomed the idea. "I told them the organization was failing slowly, and that in Silicon Valley, that's the worst way to fail," he recalls. "The longer a firm keeps failing, the less inclined that people in the Valley will be to give it the time of day."

Carter recruited two White House aides—Todd Park, a Silicon Valley entrepreneur who'd rescued HealthCare.gov, and DJ Patil, another Valley insider who'd been persuaded by President Obama to bring big data into the executive branch—and asked them to fly to California, survey the situation at DIUx, and report back on how to fix it.

Park and Patil soon had answers. First, they reported, the office needed to be able to close a deal by the end of a meeting or no more than a few days later. Second, because no one person had all the skills necessary to run something as complex as DIUx, it should be run by a senior team of four or five people who together knew about management, venture capital, technology, and the internal workings of the Pentagon. Third, this team should have a direct line to Secretary Carter himself—in part to exude authority, and in part to get approval quickly.

Finally, Park and Patil assured Carter, failure was okay in the Valley. The important thing—it's a local motto—was to "fail fast." In other words, Carter needed to shut down DIUx and reboot with as much fanfare, and as clear a sign of commitment, as possible. If he proclaimed failure forthrightly, he'd even be respected; the executives who'd looked and turned away might give the program a second chance.

On May 11, 2016, Carter flew to Mountain View and announced the start of what he called "DIUx 2.0." He also

There remained the main challenge: how to cut through the Pentagon's byzantine procurement process.

introduced the leadership team he and his staff had assembled just weeks before. They were Isaac Taylor, who had decided to give DIUx another chance after hearing assurances that his criticisms had been addressed; Chris Kirchhoff, who'd worked as a long-term strategist in Obama's National Security Council and as the civilian assistant to General Martin Dempsey, chairman of the Joint Chiefs of Staff; Vishaal Hariprasad, a highly decorated Air Force cyberwarfare officer, who later cofounded a Silicon Valley firm called Morta Security and sold it to Palo Alto Networks; and Raj Shah, who after flying F16s in Iraq had earned an MBA at the Wharton School of Business and emerged as a Valley entrepreneur, partnering with Hariprasad to start and sell Morta.

Shortly before Carter's announcement, the four met at a long dinner to discuss the terms of this new enterprise. They agreed they would take the offer under crucial conditions: they'd need hiring and firing power, authority to manage their budget, and permission to take risks and fail. (In the traditional culture of the Pentagon, managers tend to double down rather than cut their losses, accreting bloat along the way.) Carter signed off on those terms without hesitation.

PEITER ZATKO
The white-hat hacker was responsible for Cyber Fast Track at DARPA.

Discovery stage

There remained the main challenge: how to cut through the Pentagon's byzantine procurement process. All four of DIUx's leaders, as well as Carter, were inspired by the example of the Defense Advanced Research Projects Agency, which had spurred defense innovations such as the Internet itself. Particularly intriguing to them was a DARPA project called Cyber Fast Track, run by a white-hat hacker named Peiter "Mudge" Zatko. His idea was to open up R&D competitions to startups and even individuals that seldom or never worked with the Department of Defense. The result was surprising: 130 contracts awarded, between two and 16 days after first proposal, at an average cost just shy of $150,000. Some led to research breakthroughs—most notably an experiment demonstrating that Jeep Cherokees (and, by inference, all computerized cars) were vulnerable to hacking. (The cost of that contract was the retail price tag of two Jeep Cherokees and a modest fee for the two people, one of them a former NSA hacker, running the experiment.) "Mudge's Cyber Fast Track was our inspiration," Chris Kirchhoff recalls. "He

HANGAR ONE
DIUx is based on the grounds of a California Air Force base that features one of the world's largest structures, built to house airships.

COURTESY OF NASA AMES RESEARCH CENTER

showed it was possible to take an idea and award it a contract in a few days."

But DARPA is strictly an R&D cauldron. For a development project to pass into production, it generally has to be turned over to the Pentagon procurement bureaus, which, as a first step, post a wide-open competition to build a prototype. Even large, traditional defense companies refer to this gap between R&D and actual production as "the valley of death." For Silicon Valley firms, the notion was anathema: they weren't going to spend time and money developing a new technology only to lose the bid.

When DIUx 2.0 got under way, Raj Shah and his team talked to Lauren Schmidt, the program's "pathways director" responsible for contracts, who told them of a discovery she had made of enormous consequence. Previously, Schmidt had worked in the Army's acquisitions branch, where she had learned of a type of contracting blandly named "other transaction authority." In an OTA contract, the government and commercial companies can design prototype projects without the onerous rules and regulations of the traditional defense acquisition process. Congress had created this authority in the 1950s to allow the space program to "enter into and perform such contracts ... as may be necessary in the conduct of NASA's mission." But other than its use by NASA, the law had mostly languished, invoked only by DARPA (this was how Zatko rammed through Cyber Fast Track) and an Army arsenal in Picatinny, New Jersey, that manufactures guns, bullets, and precision guided missiles.

Schmidt's discovery was Section 815 of the newly passed defense authorization act, which allowed the use of OTA contracts for a wider range of projects, so long as a senior official affirmed that they enhanced the "mission effectiveness" of military personnel or their weapons systems. This changed everything. Section 815 meant that the company developing a project could take it into the prototype phase without having to endure another layer of Pentagon bureaucracy. True, the obscure article limited this expansion to contracts valued at no more than $250 million, but few of the projects that DIUx had in mind would cost that, and if they did, the new language allowed OTA contracting for those programs, too, if the undersecretary of defense for acquisition assured Congress in writing that they were "essential to meet critical national security objectives."

For the DIUx team, Chris Kirchhoff said, Section 815 "was like Thomas Jefferson taking out his pen and writing the Declaration of Independence." The pen, in this case, had belonged to a senior staffer on the Senate Armed Services Committee named Bill Greenwalt, a former Pentagon official who had written a paper likening the Defense Department's acquisition system to "an 18th-century wooden warship that has been out to sea for too long, accumulating such a surfeit of barnacles that it can barely float, let alone operate under full speed." He didn't know about DIUx when he wrote what would become Section 815, and the DIUx people didn't know about him, but their aims were the same and their purposes converged.

The partners contacted executives who'd pitched the aborted projects during DIUx 1.0—the autonomous indoor drone and the cybersecurity software—and urged them to pitch again. This time, they were approved. The drone is now being field-tested for a Special Forces unit deployed overseas.

On October 13, 2016, the new team released its first quarterly report. It listed 12 signed contracts, totaling $36.3 million, with another $100 million coming from the military services that had agreed to buy or test the products. (So far, for every dollar DIUx spent, the buyer—whatever military branch will use the device—has spent three dollars.) One of the items, made by a San Mateo company called Sonitus, is a small plastic two-way microphone and listening device that

For DIUx, Section 815 "was like Thomas Jefferson writing the Declaration of Independence."

fits over a soldier's teeth like a mouth guard and conducts signals through the bone. No earbuds are required, so soldiers dropped into a combat zone can communicate with one another while still hearing what's going on all around them and retaining "situational awareness." The contract for the device was signed at the end of the summer; by October, the Air National Guard was using it in Afghanistan.

For the 12 projects, the average time between the initial proposal and the signed contract was 59 days. All the products were designed for commercial markets—the companies involved hadn't even thought about possible military applications—and no one in the military had been aware that the products or the companies existed. It was DIUx that put the two together. All this was a radical departure from standard practice. Under typical Pentagon contracting procedures, the military services write a "requirement," which bureaucrats translate into a "request for proposal," to which corporations respond with product designs, which another layer of bureaucrats evaluate, and on it goes until competing prototypes are introduced. The officers who write the original requirements never speak to the corporate managers who manufacture the resulting hardware or software.

Isaac Taylor says, "I spend lots of time traveling to military groups. I ask, 'How can I help? Where is the technology acquisition system not meeting your needs?' No one has said, 'No, thanks, I'm doing fine.' They all say, including the most senior officers, 'We'll take all the help we can get.'"

These are precisely the sorts of conversations Ash Carter hoped the project would provoke. "My intent with DIUx," he says, "is to ensure there are more people who are able to understand both universes and to bridge them: those who come from the tech community and contribute to our vitally important mission and those already part of the Defense Department who get to know the technology world better."

One pleasant surprise has been the large number of firms that have expressed interest in the program. Silicon Valley is often painted as a landscape populated by cyber-libertarians, hostile to the national-security state, but Raj Shah insists the stereotype is overstated. "Silicon Valley was built on a private-public partnership in national security, and I'd love to rebuild that," he says. "There's certainly skepticism about whether it will work; but there's not as much skepticism as people think about the broad value of the military."

Since the summer reboot, DIUx branches have opened in Austin and Boston. An office in Kendall Square in Cambridge, Massachusetts, is now headed by Bernadette Johnson, who took a leave of absence from her job as chief technical officer at MIT's Lincoln Lab to become chief science officer of the program. While the headquarters has devoted most of its efforts to robotics and drones, the focus in Boston is on biotech and biomedicine. "It turns out there are lots of reservists at Harvard labs and Boston hospitals," Johnson says. "I'm optimistic about our growth."

"I ask, 'How can I help? Where is the technology acquisition system not meeting your needs?'

Existential doubts

The presidency of Donald Trump throws these prospects—perhaps the very existence of DIUx—into doubt.

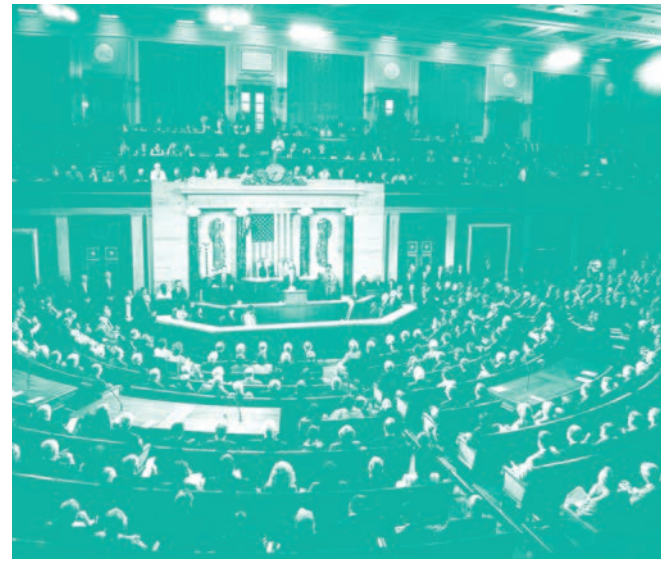
New administrations often scrap the programs of their predecessor, especially if headed by the opposing party. During the campaign, DIUx managers reached out to both candidates' staffs: they briefed some of Hillary Clinton's defense advisors, who seemed happy with the program, but they weren't able to sit down with anyone on Trump's team, because there were no defense advisors to brief. Trump's pick for secretary of defense, retired Marine general James Mattis, has a strategic mind and a penchant for innovation,

and he really cares about the needs of those in the field. He might embrace DIUx.

Even before the election, there was nail-biting in Mountain View. In 2016, the House Armed Services and Appropriations Committees eliminated the program's budget for the next fiscal year. Secretary Carter urged them to restore funding. The Senate committees have approved full funding, but the House-Senate conference committees will make the final decision. Some observers are optimistic. The House panels made their cuts after learning of the unit's initial failures, and justifying its existence was why DIUx rushed out its report on the 12 contracts in October: it wanted to show Congress that the program was succeeding.

But some members of the committees, especially those from the House, prefer the old way of doing things. So do the big defense corporations that molded their structures and procedures to fit the regulations of the Pentagon's procurement bureaucracy.

The perception that DIUx might disrupt the Department of Defense's settled ways is not entirely unreasonable. Frank Kendall, the undersecretary of defense for acquisition, who



UNCERTAIN FUTURE
No one knows whether the new Congress will continue to fund DIUx.

No one has said, 'No, thanks, I'm doing fine.' They all say ... 'We'll take all the help we can get.'"

once was unimpressed with the outfit in the Valley, now touts its strengths. On November 21, he sent an "all-hands" e-mail headed "New Rapid Contracting Tool." The message encouraged "all acquisition professionals to familiarize themselves" with the OTA contracting approach, praised DIUx for using the method "to rapidly meet warfighter requirements," and announced that the Department of Defense had asked Congress to approve "an expansion of this authority" to cover emerging "state-of-the-art" technologies, not just those stemming from commercial projects.

The communiqué was not a memo or a directive. The sort of contracting it champions does have its limits. Ash Carter emphasizes that OTA isn't suitable for every weapons program. "We're not going to use DIUx to procure aircraft carriers or the F-35," he says. But he adds that he does hope DIUx has "a transformative impact" on the Pentagon's procurement practices broadly, encouraging its bureaucrats "to embrace a culture of innovation." To some people, that's not a hope but a threat.

Small, still-nascent programs that haven't built up sizable constituencies often need support at the top to survive. DIUx has been Ash Carter's pet. It's hard to say whether the next secretary of defense will give it the same attention. But the inadequacy of the present system is clear. Raj Shah recently traveled to the Middle East to talk with U.S. commanders about DIUx projects. He made a point of talking with some F16 pilots who are flying combat missions over Iraq, just as he did 10 years ago. Their jets had been upgraded with moving maps. But not long before, they had still been strapping iPads to their laps, after loading them with commercial aviation map apps, so that they knew exactly where they were flying.

Fred Kaplan is the "War Stories" columnist for Slate *and the author of* Dark Territory: The Secret History of Cyber War.

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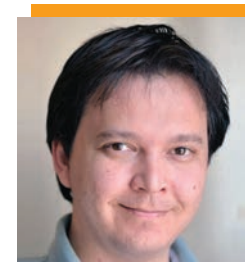


Ruslan Salakhutdinov

Carnegie Mellon University

The Promise and Limitations of Machine Learning

Ghana's Mile

Innovative African e-tailers are offering sought-after goods to the continent's growing middle class. But logistical challenges must be worked out delivery by delivery.

By Jonathan W. Rosen

Photographs by Francis Kokoroko

Last

Mohammed Sani Ali delivers packages in Accra, Ghana's capital city, for the online shop Tisu. His motorbike has a red box on the back.

Inset: After ordering online, a customer pays in cash at a pickup location run by e-tailer Jumia in Accra's Makola Market.

Michael Ashong, who delivers packages for Accra's online marketplace Tisu, tries to reach a customer.

It's the peak of the afternoon in Accra, the capital of Ghana, and Michael Ashong is growing restless. A delivery driver for Tisu, a local online merchant, he's spent much of the day in a compact black Hyundai hatchback delivering shoes, smartphones, and other consumer items across the city, with me riding along. Now Ashong's final delivery is proving difficult. Like most drivers in the city, he navigates by landmarks: Accra's streets are generally well marked, but few buildings have numbers, and most people here don't use the official address system. Ashong's last customer, a student at a nursing school on the city's outskirts, hasn't been able to guide him from the sights he shouts into his phone: the main gate of a hospital affiliated with the school; a row of derelict buildings; "the place where they sell yams." At one point Ashong flags down a passerby, who speaks to the customer on his phone, but the resulting directions only lead him further off track. After 30 minutes of driving in circles, Ashong and his customer finally agree on an alter-

Top: Customers who place orders online can pick them up in person at Tisu's location in East Legon, a suburb of Accra.

Bottom: Mohammed Sani Ali at an Accra bus depot unpacking packages that he will send to customers in the town of Kumasi, 150 miles away.

Opposite page: Tisu prints a catalogue to promote its Groupon-style online deals.

native meeting spot, and the customer arrives to pay cash for his package. In the end, the delivery, including round-trip travel, takes nearly two hours, all for a "Moon Love" necklace costing 49 Ghanaian cedi ($12).

"These are the challenges we get to," Ashong tells me as we return, windows down in the tropical heat, to Tisu's logistical hub and office in the suburb of East Legon, northeast of the city center. "At least the customer was [answering his phone]. Sometimes you get there and his phone is off. I normally try three times and then I have to move."

Ashong, a soft-spoken 28-year-old who trained as a mechanic and used to drive a taxi before coming to work for Tisu, is the navigator of his employer's last mile, the final link in a supply chain that starts with manufacturers around the world, traverses sea and land to the shelves of Accra vendors, and finally arrives at Tisu's hub. There high-volume items are kept in stock, others are collected on order, and all are eventually parceled out to one of the five drivers the company employs directly.

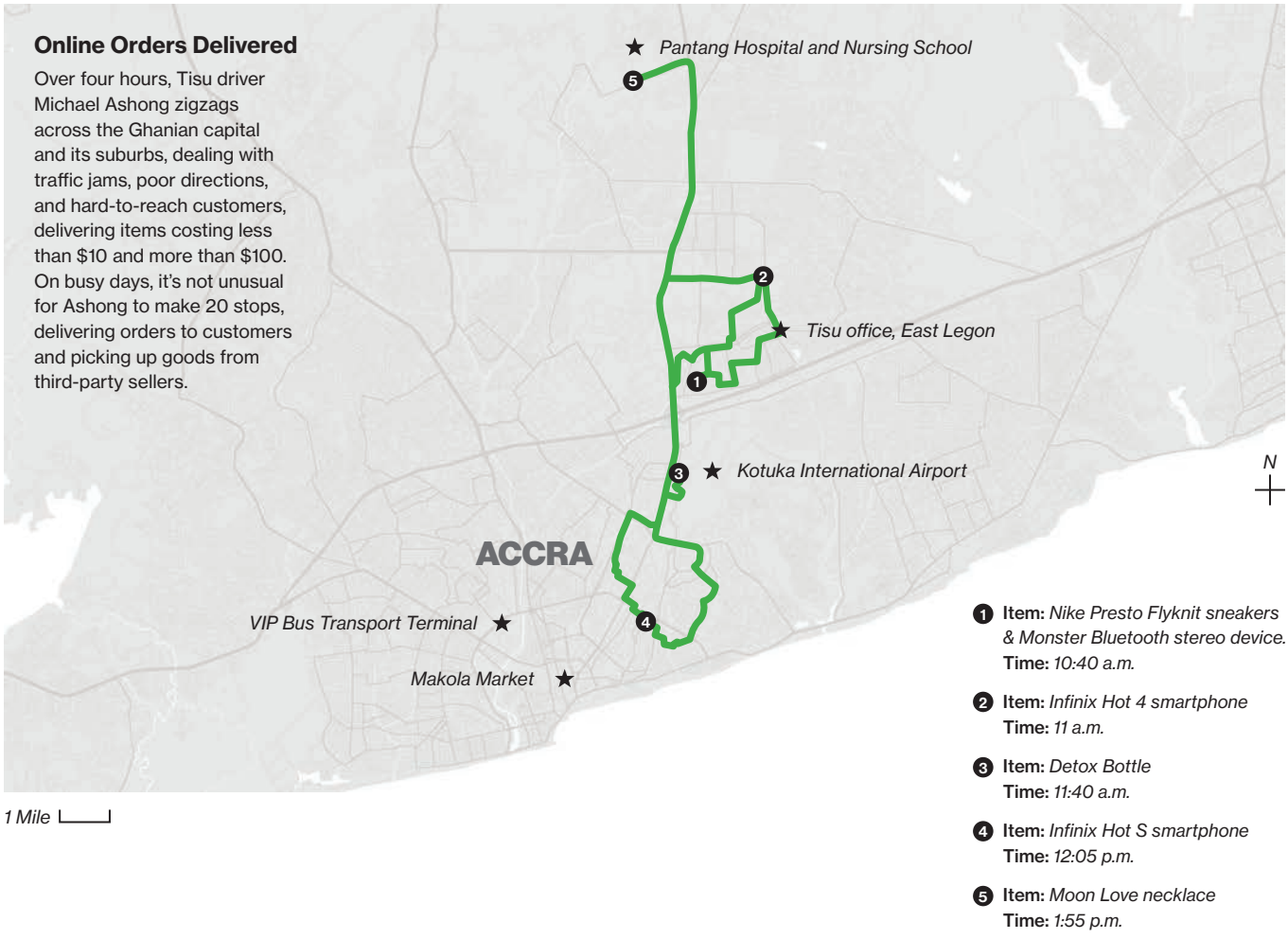
Shopping online is still a novelty in Ghana, as it is in much of Africa: fewer than 1 percent of African retail sales are made online. Yet rising purchasing power across much of the continent, buttressed by years of strong economic growth, has boosted demand for Western consumer goods faster than Africa's limited brick-and-mortar retailers can supply them, especially since traffic congestion in many cities makes trips to the mall untenable. Meanwhile, smartphones and access to high-speed Internet are increasingly common. All this means African e-commerce has started to grow. Earlier this year, the sector reached a watershed moment when Jumia Group, formerly Africa Internet Group (see 50 Smartest Companies 2016), the parent company of Africa's largest e-retailer, Jumia.com, became the continent's first tech "unicorn," surpassing $1 billion in market value. Like much of Africa's online economy, Jumia has gotten its funding primarily from large international corporations, among them French insurer Axa, Wall Street leviathan Goldman Sachs, German technology investor Rocket Internet, and South Africa's top telecommunications company, MTN Group.

All these companies are betting that growth in Africa's online economy will accelerate. McKinsey, the global consultancy, predicts that in the continent's largest economies, 10 percent of retail sales could be transacted online by 2025. That's greater than the proportion in the United States today and would translate to $75 billion in sales a year. "In the long term, there's no question that e-commerce is going to be massive in Africa," says Jørn Lyseggen, founder and chairman of the Meltwater Entrepreneurial School of Technology, an Accra-based incubator of technology startups.

But getting there will require companies to overcome many problems like the ones I saw Ashong facing.

His employer, a Groupon-style deals site owned by the Swiss–South African venture Ringier Africa Deals Group, has grown steadily since its launch in 2011 and now draws 250,000 visitors per month. Its focus is mainly fashion, home décor, and electronics.

Its greatest competition comes from Ghana's traditional marketplaces. Downtown Accra's sprawling Makola Market, far from Tisu's quiet suburban hub, contains everything from Chinese-sourced wigs and plastic kitchenware to live crabs and local kente fabrics—sold from sidewalks, partially covered stalls, or the tops of women's heads. Hawkers cluster at



intersections selling sunglasses, earbud headphones, and coconuts out of push-carts. Tin-roofed shops displaying sneakers, dress shirts, sofas, and the occasional parrot cling to the edges of highways and tree-lined boulevards.

Many of the goods there are second-hand or cheap knockoffs, which leaves Ghanaians of means in want of more upmarket alternatives. Although metropolitan Accra, with a population of four million, now boasts several modern shopping malls, many people wait to make purchases on overseas trips or rely on family in the diaspora. Even Ashong sources much of his wardrobe from abroad. "I have an uncle in New York," he tells me when I ask about his fashionable loafers. "I usually wait for him to visit."

For Ashong's customers, who've had Tisu products delivered to their homes, businesses, and classrooms, searching for products online is faster than waiting for a family courier's visit and more convenient than fighting traffic to get to a mall or market. Nelson Amo, the CEO of a local investment firm and Ashong's second client of the day, says he prefers the site because it saves him time and he's confident its products are "verified." Today's delivery, an Infinix Hot 4 smartphone ordered less than 24 hours earlier, is the third order he's made from Tisu. It arrives without the screen protector he had expected—essential to prevent his kids from "crushing it"—so he'll have to place his fourth.

For many Ghanaians, though, a lack of trust in online retail remains a significant deterrent. The vast majority of Tisu customers pay with cash on delivery, in part because few of them have a credit card or mobile money app, but also because most Ghanaians prefer to have a product in their hands before they commit to buying it. Augusta Davis, head of operations and customer service for Tisu, says the company has had problems with customers placing orders simply to "test the site," only to refuse the products on delivery.

Internet penetration in Ghana is relatively high—the National Communications Authority counts 18 million mobile data subscribers, equivalent to 66 percent of the population—but data bundles are expensive and memory is limited on many popular phones, deterring some from downloading apps for making pur-

Bustling Makola Market in the center of Accra.

Makola Market vendors sell everything from sunglasses to pet birds, but many of the goods are second-hand or cheap knockoffs.

Mohammed Sani Ali rides a motorbike to deliver packages in Accra, where heavy traffic makes car travel difficult. His route also includes this depot where he sends packages on public buses to customers in Kumasi.

Tisu's Mohammed Sani Ali.

Makola Market.

Michael Ashong delivers a package and takes payment in cash.

chases. To overcome that challenge, Tisu produces a print catalogue that it leaves at restaurants, salons, and other strategic points around the capital. Jumia goes a step further, employing a network of commissioned sales agents, called J-Force, to place orders for clients who have limited online access or are not comfortable ordering themselves. "J-Force gives a human touch to what we do," says Francis Agbemey, who manages the network in Ghana.

Arguably the biggest barrier to online retailing—bigger even than cultural norms or limits on connectivity—is the one Ashong faces daily: the challenge of delivery. In Accra, where the bulk of the country's affluent citizens are concentrated and where the lion's share of Tisu's orders come from, traffic is so bad that e-retailers make most of their deliveries on motorbikes, which can more easily maneuver through congestion. Ashong, Tisu's only driver on four wheels, says he saves time by making use of the city's "short ways" and "corners"—deviating from the well-maintained primary routes onto back roads that are unpaved or full of potholes.

The day I ride with Ashong, he drives for four hours through quiet suburbs, office parks, and hectic downtown streets, but he manages just five deliveries and two pickups from third-party vendors. (On busy days, he says, the total can rise to 20.) Ashong tracks down every customer, and all accept their products. Even the day's final client—the nursing student, Samuel Akuffo, who's had to leave a quiz to come and find us—is forgiving of the hassle required to get the necklace.

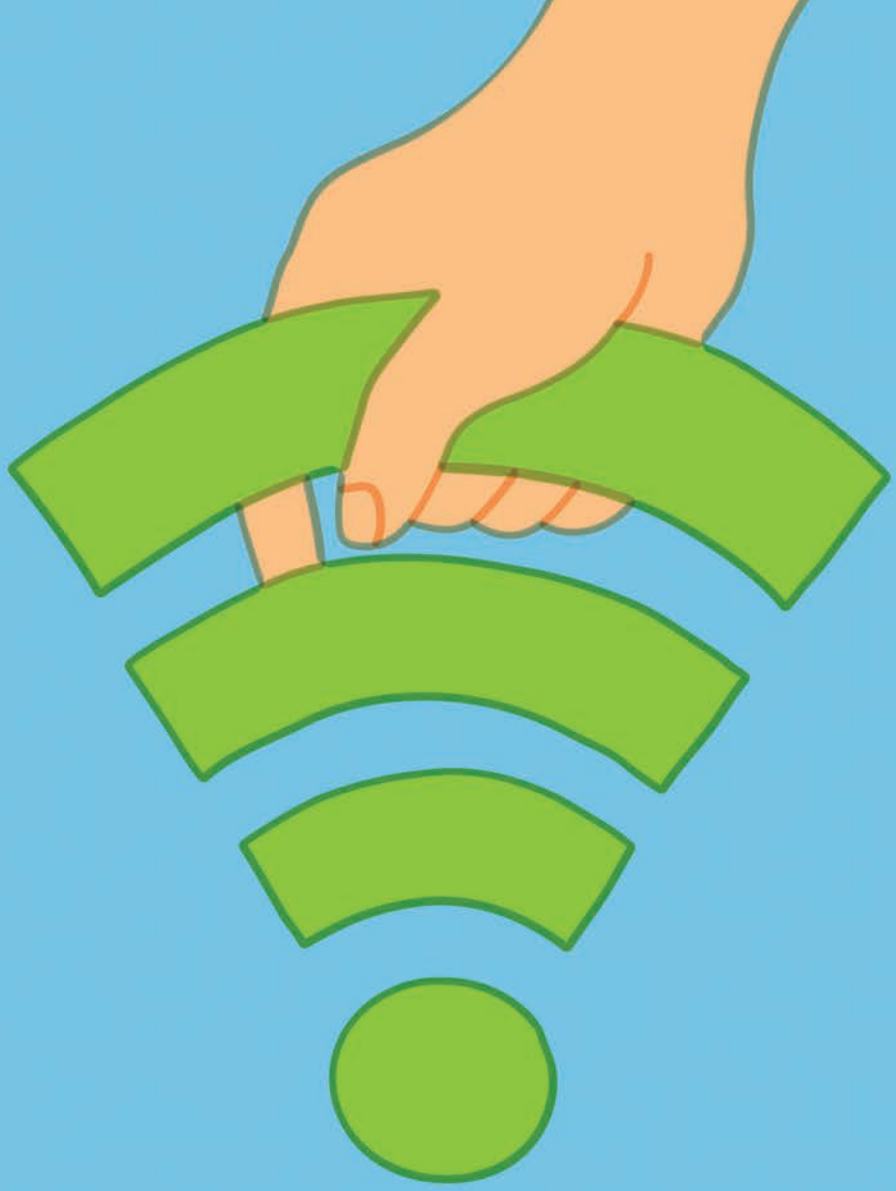
"My girlfriend's birthday is on Saturday," he explains. The gift was his first Tisu transaction, made on his smartphone via the company's Android app. "I looked at the deals and it was cool."

Ashong then offers Akuffo a ride back to his classroom, and he sighs as our new passenger directs him onto a dirt road we'd missed before, not far from the yam seller. We arrive, and Akuffo rushes to rejoin his class. "Next time," he tells Ashong, "you'll know where to find me."

Jonathan W. Rosen is a journalist covering sub-Saharan Africa. He is a 2016 Alicia Patterson Foundation reporting fellow.

The Hole in the Digital Economy

By David Talbot



If the next president intends to improve American infrastructure and expand economic opportunities, there's no better place to start than with the millions of people who still lack broadband access and computer skills.

TIM LAHAN

Most homes in the United States have Internet service, but they don't in the poor parts of Cleveland and nearby suburbs. A survey in 2012 showed that 58 percent of the area's households with incomes under $20,000 had neither home broadband nor mobile Internet access, often because of the cost. Another 10 percent had a mobile phone but no home broadband. Until recently, one such household was a ground-floor two-bedroom apartment in a public housing project called Outhwaite Homes, where a circumspect 13-year-old girl named Ma'Niyah Larry lives with her mother, Marcella.

Ma'Niyah has a special-education plan for math; to help her, she's been assigned problems to do online through Khan Academy. But her mother says she cannot afford broadband from Time Warner Cable, which would begin at around $50 a month, even for an entry-level offering, plus modem and taxes (and the price would rise significantly after the 12-month teaser rate expired). The family has a smartphone, but it's harder for Ma'Niyah to use the small screen, and Marcella watches her data caps closely; just a few hours of Khan Academy videos would blow past monthly limits. Fast Internet access is available in a library a few blocks away, but "it's so bad down here that it's not really safe to walk outside," Marcella Larry says. Ma'Niyah's bedroom, its wall decorated with a feathery dream-catcher, faces a grassy courtyard where gang-related gunfire rang out on two nights last summer, causing Ma'Niyah to flee to the relative safety of the living room.

There is a patchwork of attempts to deal with this problem. The region's public housing agency, the Cuyahoga Metropolitan Housing Authority, recently gave Ma'Niyah a tablet and a wireless hotspot in a trial program to help close the "homework gap" that's opened up between kids who have Internet-connected computers at home and those who don't. And Marcella Larry qualifies for a discount program AT&T offers to families that receive food subsidies: DSL service—far slower than what the government defines as broadband—over phone lines for $5 to $10 a month. But it's hardly a long-term solution. AT&T agreed to offer the package for four years as part of its effort to win regulatory approval for its acquisition of DirectTV.

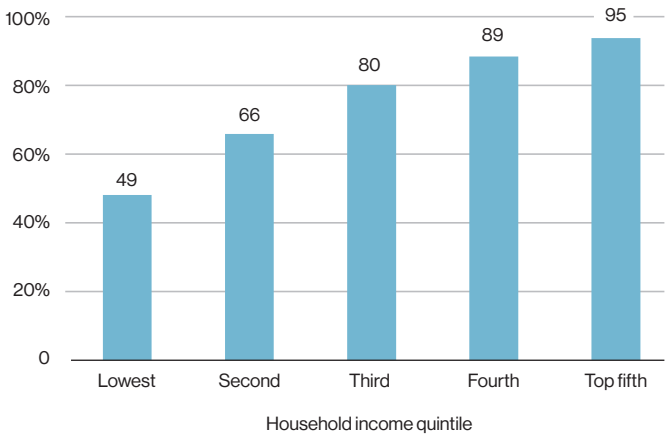
Marcella and Ma'Niyah are among the millions of people on the wrong side of America's persistent digital divide. A survey by Pew Research shows that fully one-third of American adults do not subscribe to any Internet access faster than dial-up at their home at a time when many basic tasks—finding job listings, doing homework, obtaining social services, and even performing many jobs—require being online. Even many people who are willing to pay for service can't get it. Thirty-four million Americans have no access at all to broadband as the U.S. Federal Communications Commission defines it: a download speed of at least 25 megabits per second and an upload speed of three megabits per second. These speeds are what FCC chairman Tom Wheeler calls "table stakes for 21st-century communications."

People without broadband are not necessarily entirely offline: like Marcella Larry, some of them rely on smartphones. But because of small screens and data caps, phones are not an adequate substitute for home broadband. Its absence in some communities is a growing problem at a time when the jobs of the future will be increasingly digital: the Bureau of Labor Statistics projects that 500,000 information technology jobs will be created in the next few years. Already, one in 20 American adults is deriving some income from online "gig" employment (not including ride- or home-sharing services), according to joint studies by Microsoft Research and the Pew Research Center. Such opportunities are only expected to grow—for people who have broadband access.

In Cleveland, which along with Detroit ranks among the worst-connected cities in the nation, help is on the way for some residents. Housing projects like the one where Marcella and Ma'Niyah Larry live are about to benefit from an ambitious project to provide the fastest service in the city using a combination of fiber-optic networks and a new breed of wireless connection. But no comprehensive solution is in evidence for these cities—or the nation as a whole. Despite having invented the Internet's proto-

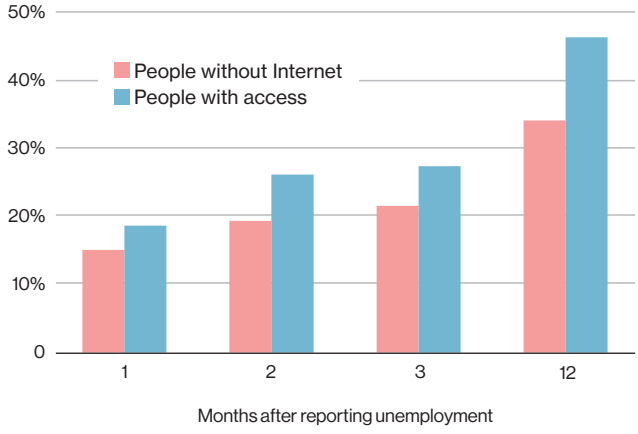
Internet Use at Home by Income

While nearly all wealthy U.S. households are online, only about half of the poorest ones are.



DATA FROM COUNCIL OF ECONOMIC ADVISERS, CITING CENSUS FIGURES AND SURVEYS IN 2014

Percentage of Unemployed People Who Found Work
People who said in labor surveys in 2010–2013 that they were unemployed were likelier if they had Internet access to say in subsequent surveys that they had jobs.



DATA FROM COUNCIL OF ECONOMIC ADVISERS

cols, the United States lags far behind much of the industrialized world in available broadband speeds and affordability of fast services—a problem that is particularly acute in inner cities and rural areas. In past eras, great national efforts led to universal electricity and telephone service. Now the nation could use an ambitious plan to improve service, drive down costs, and expand access to children like Ma'Niyah and everyone else who deserves it.

Opening doors

Of course, computers and broadband by themselves don't magically lead to college degrees and better jobs. After all, much of what people do with Internet access once they get it is hardly productive. But some of them may not be getting the training they need to make effective use of software and online services. And there are many correlations between broadband access and income levels or success in finding employment. As the White House Council of Economic Advisers says, "The digital divide is likely both a cause and a consequence of other demographic disparities."

When people do get broadband and computer training, their lives can change in remarkable ways. Take Monica Moore. She's a single mother who lived in a decaying neighborhood on the east side of Cleveland and spent more than 20 years working as a file clerk at the Cleveland Clinic. Then three years ago came ominous news. "At work, they said everything was going to electronic medical records and they were going to outsource my job," Moore, now 47, recalls. "Oh my gosh, my job."

Moore had few computer skills and rarely used the Internet. The high cost of service from Time Warner Cable kept her offline. But faced with the prospect of losing her job, she steeled herself and entered a storefront training center called the Ashbury Community Center. She started learning software like Office and Excel, and wound up taking online classes through the University of Phoenix. She spent evening after evening doing that work until, in early 2016, she collected a bachelor's degree in finance. She was one of more than 6,000 people who have received computer training over the past five years thanks to the Ashbury Center and its partners in a nonprofit collaborative called Connect Your Community.

Today, she's still at the Cleveland Clinic—only she's got a new job that pays $20,000 more than her old one, editing and uploading digital reports in the hospital's bustling cardiac catheterization lab. "I was stuck 20 years in the same job due to the fact I didn't have the means, the technology," Moore says. "This opened so many doors for me, and I'm just so thankful." While finishing her degree, she recognized the value of getting Internet access at home. She decided it was worth $154 a month for a cable deal that includes high-speed access in her new home in the suburb of South Euclid.

Fast and cheap

To solve the access problem for more low-income people, Cleveland needs to focus on public or subsidized housing, where 50,000 of the city's 375,000 inhabitants live. I took a trip to the 14th-story roof of a public housing project named Cedar Estates with Lev Gonick, CEO of a local nonprofit called DigitalC. We stepped out into the drizzle and beheld a panoramic view of America's industrial rise and decline. To the north was Terminal Tower, a symbol of the region's onetime economic might: the 52-story Art Deco tower was once the second-tallest building in America. To the south, smoke rose from two steel mills that represent the vestiges of a local industry that today employs fewer than 2,000 people, down from Cleveland's steelmaking peak of 47,000. Also in sight: vacant factories and blocks of near-worthless frame houses.

Gonick pointed to St. Vincent's Charity Hospital, one kilometer away. A high-speed fiber-optic network passes through St. Vincent's; built using a 2009 federal stimulus grant, it connects institutions including at least 800 schools, medical facilities, and government buildings in greater Cleveland. Now the plan is to extend the network to residents in the housing projects. Because it would cost $350,000 to run fiber from St. Vincent's to Cedar Estates and several nearby buildings, DigitalC will instead close that gap with a wireless technol-

ogy costing one-tenth as much to install: a millimeter-wave transmission system from a company called Siklu. The new service will be able to deliver one-gigabit-per-second connections to the building, and a bank of servers in Cedar Estates' basement telephone room will use the existing copper telephone network to provide broadband service to all 163 apartments.

The goal: to provide the fastest and cheapest service in the city, completely removing the cost barrier that poor residents now face. Gonick believes the whole project is so cheap to build that when you throw in an FCC subsidy (called "lifeline") of $9.25 per month, all tenants in the housing project will easily be able to afford broadband.

While delivering fast, cheap service is an end in itself, DigitalC and partners also plan to give all tenants in the Cuyahoga Metropolitan Housing Authority refurbished computers and training similar to what's offered at Ashbury. The tenants will be directed to online workforce training schools such as Career Online High School, too. At the same time, the government of Cuyahoga County is working to put more services online, including workforce training, benefits enrollment, and potentially telemedicine appointments, says Scot Rourke, chief transformation officer for the county. "We want to do more than manage poverty," he says. "If we have broadband, we can do more kinds of education and training. We've got to get people into jobs that will give them the wages to get out of poverty."

Paths to such jobs exist for those who seek them. One of the new businesses within Terminal Tower is WeCanCodeIt, a 12-week software engineering boot camp for people with little experience in technology. The program aims to equip them for jobs like building websites. One student is Melissa Hughes, 40, who left her job as an HIV-testing counselor in Philadelphia and is now unemployed in Cleveland. "In my previous field there was not stability," she says. "Adding coding skills will give me more opportunity."

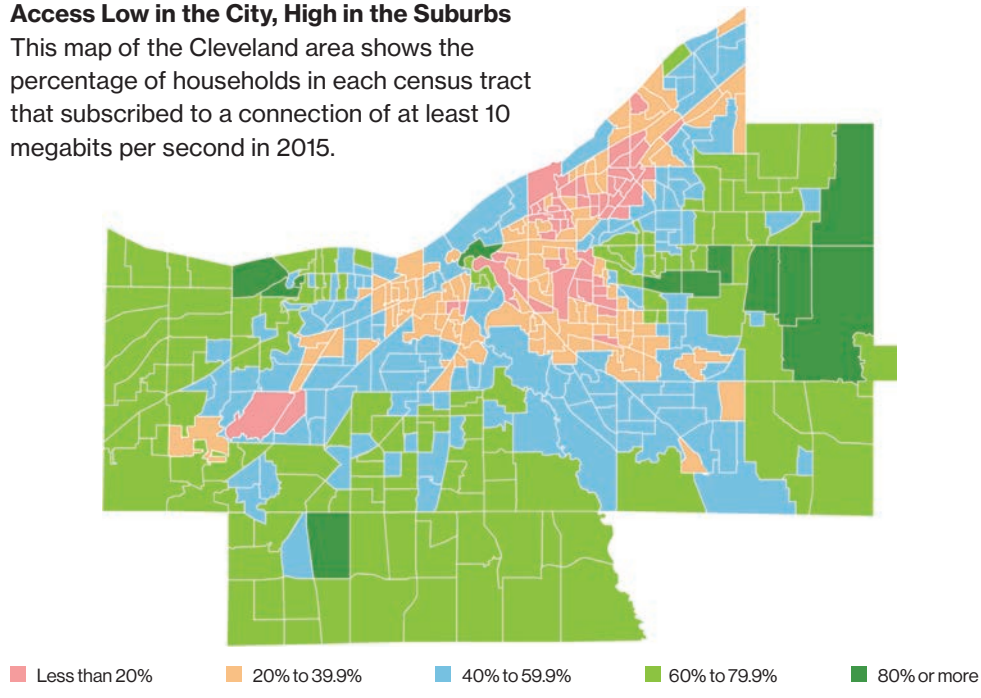
New efforts to introduce kids to coding are taking root as well. At a recent "hip-hop coding" seminar organized by several academic institutions in a downtown office space, teachers and librarians photographed themselves doing break-dance moves and then used Scratch, the popular programming language and online community developed at MIT, to design multimedia animations of their antics. Maria Trivisonno, a librarian in the Cleveland suburb of Warrensville Heights, explained the audience she had in mind: the kids who pour into the library after school, looking for things to do. "We want to teach kids how to create things online, not only how to find information," she said between dance moves. "If you can start kids young thinking about how to code, it will help them as they get older."

Don't be scared

While Gonick's project might provide a model for cheap broadband in public housing and for educational efforts that might help people put it to good use, there's a bigger problem to crack: how can we get more and cheaper digital infrastructure everywhere else in the country? The key is to stimulate competition. For example, after Google began offering broadband on fiber-optic lines in the Kansas City area in 2012, existing providers increased the speed of their services by 86 percent over what it had been a year prior—the largest increase in the country at the time, according to Akamai Technologies.

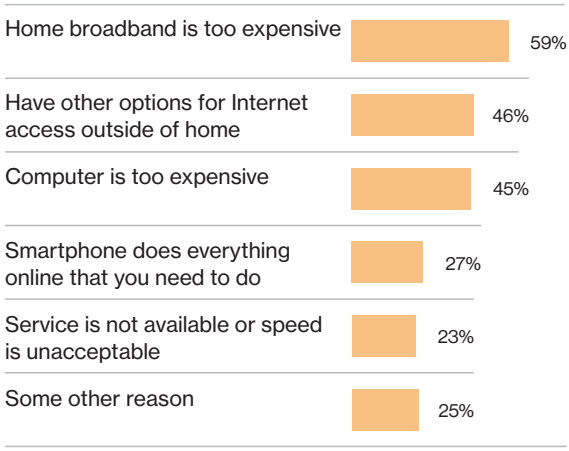
But Cleveland has no such luck. It has only two compa-

Access Low in the City, High in the Suburbs
This map of the Cleveland area shows the percentage of households in each census tract that subscribed to a connection of at least 10 megabits per second in 2015.



MAP BY CONNECT YOUR COMMUNITY 2.0 USING FCC DATA

Why Don't You Have Broadband?
People who don't subscribe usually cite cost as one of their reasons.



DATA FROM PEW RESEARCH, 2015

nies providing service—Time Warner Cable and AT&T—and the latter doesn't compete very strongly. AT&T doesn't offer most of the city anything close to what the FCC considers broadband, and some streets can still only get dial-up service from the company.

The situation is perhaps worse in rural areas. Drive an hour east of Cleveland and you reach the community of Andover, flanking the Pennsylvania border. Much of the region has only slow DSL from CenturyLink. "They claim it's 'high speed,' but downloading things literally takes minutes," says Cindy Schwenk, a retiree who works part time at the Andover Public Library. When she's there, she can use Wi-Fi to download things on her smartphone in just seconds because the building, unlike residences in the area, has a fast connection from a state library consortium. People sometimes sit in their cars outside the building after hours to get online.

The Andover area relies economically on part-time residents who vacation at nearby Pymatuning Lake. But other areas without such draws may get left behind in an increasingly digital economy.

How can we jump-start competition in these places? One model is emerging: let local governments find partners to build out the basic fiber-optic infrastructure, or at least the empty conduit that can carry fiber underground, and then let service providers compete for customers over such networks (or pull fiber through the conduit, as the case may be). That's what a few cities are doing, including the aerospace mecca of Huntsville, Alabama. In this case, what's going on in Huntsville isn't rocket science. The city is building the basic fiber infrastructure, known as "dark fiber"; Google will "light" the fiber and provide the service. In Ammon, Idaho, the city built a fiber network and let private service providers duke it out. Now customers can use a Web interface to switch providers in a few seconds. No need for the company-specific cable or optical networking boxes that are common in homes across the country.

But in most places, efforts to install new networks often crash into decidedly low-tech obstacles. For example, utility poles. These are almost always owned by an electric company or telephone company, and the latter has an interest in making it slow and costly for competitors to add new fiber to the poles. The FCC has streamlined the rules for how companies attach to poles, but under federal law the rules benefit only ISPs, telephone companies, and cable companies. If the entity trying to install fiber happens to be, say, a county redevelopment agency in a rural area, FCC regulations don't apply, and pole owners are freer to make the process lengthy and difficult, even if the agency has been told by the state or local government that it may use the poles. Cutting red tape to help install fiber and then adopting flexible service models to facilitate competition could "help get away from today's rigid models of information services," says Christopher Mitchell, director of the community broadband networks initiative at the Institute of Local Self-Reliance, a nonprofit that, among other things, studies broadband. That might finally help end the digital divide across the United States.

Does everyone deserve access to affordable high-speed Internet, just like water, sewers, electricity, and telephone service? In Ma'Niyah Larry's apartment and at the Ashbury Community Center, where Monica Moore rebooted her career, you can see that the argument could be made. "There is never a shortage of people who want to show up here and learn," Bill Callahan, director of the Connect Your Community collaborative, remarked as we looked around the community center.

One of those people was Claudette Hughley, a 55-year-old unemployed physical-therapist assistant and mother of three adult children. She has spent her life offline and needs to find work. She's now learned how to use e-mail, how to create and edit Word documents, and how to scroll through online job listings. These are all steps toward fully crossing the digital divide.

"I'm just getting more comfortable with doing things like this," she said. "I want to broaden my mind—and not get scared."

David Talbot is senior writer at MIT Technology Review *and a fellow at the Berkman Klein Center for Internet & Society at Harvard University.*

Mining Without Miners

Each of these trucks is the size of a small two-story house. None has a driver or anyone else on board.

The mining company Rio Tinto has 73 of these titans hauling iron ore 24 hours a day at four of its 15 mines in Australia's Mars-red northwest corner. At this site, known as West Angelas, trucks work alongside autonomous rock-drilling rigs.

Some economists say that improvements in robotics are set to sweep many workers out of roles that machines were once unable to fill. Mining could be among the first sectors in which that prediction comes true across the board.

Automation is attractive to companies like Rio Tinto because mining is a dirty, dangerous business ruled by a lust for efficiency. Driverless machines can improve productivity while reducing the costs and constraints that come with human workers, who need to be kept safe and well rested. Although even the best software isn't yet capable of driving unsupervised on public roads, mines offer more controlled environments that can be made robot ready today. BHP Billiton, the world's largest mining company, has its own driverless trucking and drilling program in Australia. Suncor, Canada's largest oil company, is testing driverless trucks on the oil sands of Alberta.

Rio Tinto's automated trucks use detailed maps and precision GPS to get around. The vehicles and their robotic-drill coworkers are choreographed from an operations center 750 miles to the south in the city of Perth. A single staff member can monitor and direct dozens of trucks. And this is just the beginning. Rio Tinto is upgrading the locomotives that pull trains laden with ore from mines to ports so that they, too, will be driverless, and loaded and unloaded automatically. *—Tom Simonite*

COURTESY OF RIO TINTO

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Amazon's Next Big Move: Take Over the Mall

Unable to resist any opportunity to sell you something, the e-commerce leader is opening up brick-and-mortar bookstores. But its online prowess doesn't yet translate into a very good retail experience.

By Nicholas Carr

SOPHIA FOSTER-DIMINO

As I pull my phone from my pocket and start snapping pictures, I feel like a private eye, or even a secret agent. I've just walked into Amazon Books, the Web giant's flagship bookstore in Seattle, but my intentions have little to do with shopping. I'm on a reconnaissance mission.

Like many authors, I have a love-hate relationship with Amazon. The love is transactional. Amazon sells about a third of all printed books purchased in the country, and some two-thirds of all e-books. The hate is a form of mistrust. The company's size gives it immense power, and it has at times acted like a predator, trying to dictate the terms of bookselling while showing contempt for the traditions of publishing. I'm not entirely sure whether Amazon wants to be my benefactor or my undertaker.

So here I am, behind frenemy lines, taking photographs of shelving.

After a half-dozen shots, I stow the phone and approach one of the four clerks in the store, a solicitous young man with a slightly antsy demeanor. He smiles when I ask why the leviathan of virtual retailing would bother opening a store in the real world. "We've accumulated 20 years of data on bookselling," he replies, then adds, "And Jeff Bezos really, really loves books." I sense he's said these things before. I inquire about the store's design, and he explains that it was modeled on the Amazon site. All the books are displayed with their covers facing outward, a visual echo of the thumbnail images that crowd the Web store. Beneath each volume is a small placard that displays the book's Amazon star rating—only books that have earned at least four stars from Web buyers are stocked—and that also includes a brief excerpt from a customer review. One of the store's displays offers "If you like this, you'll love this" sug-

gestions, a play on Amazon's recommendation engine, while another promotes new books that racked up a lot of preorders online.

I wander to the center of the store, between the fiction and nonfiction sections, and find a series of low tables displaying, in Apple Store fashion, samples of various gadgets that Amazon sells under its own brand. There's the Kindle Paperwhite e-reader, the Fire HD tablet, and the Echo voice-activated virtual assistant, along with a selection of headphones, wireless speakers, and other accessories. At the head of the hardware aisle, facing the shop's entrance, is a big television running Fire TV, Amazon's set-top streaming box. A little boy is sitting on a bench in front of the screen, engrossed in the video game Crossy Road.

What's Amazon doing with Amazon Books? That question has hung in the air ever since the Seattle store opened in November 2015. Speculation about the company's motives intensified during 2016 when it opened two more bookstores, in San Diego and Portland, Oregon, and divulged plans for more in Chicago and suburban Boston. Since Amazon has said little about its strategy (it ignored my requests for comment), Wall Street analysts and tech writers have filled the void with conjecture. The stores are all about selling gadgets, goes one popular idea, with the books there just to lure customers. The stores are data-gathering machines, goes another, enabling Amazon to extend its tracking of customers into the physical world. Or maybe the company's secret plan is to use the stores to promote its cloud computing operation, Amazon Web Services, to other retailers.

The theories are intriguing, and they may contain bits of truth. But the real impetus behind the stores is probably much simpler: Amazon wants to sell more books.

Not long ago, the common wisdom held that Amazon would remake the book business in its own image. Its Web store would kill off bookstores, and its Kindle would render physical books obsolete. In an interview in 2009, 18 months after the Kindle's launch, Jeff Bezos suggested that the "great 500-year run" of the printed book was coming to an end. "It's time to change," he declared. Readers had a different idea. After an initial boom, sales of digital books went flat and then started to fall—in the mainstream trade-book market, e-book revenues dropped 11 percent in 2015 alone, according to the Association of American Publishers—while sales of printed books, far from collapsing, held steady. Bookstores, too, have been making a comeback, led by small, independent shops. According to the U.S. Census Bureau, sales in bookstores grew 2.5 percent in 2015, the first uptick since 2007, and the growth rate strengthened to 6.1 percent during the first half of 2016. The number of newly opened bookshops has also been on the rise.

Amazon Books
Stores open in Seattle, San Diego, and Portland, Oregon; stores planned for Chicago and Dedham, Massachusetts

Bezos underestimated the allure of bricks and paper. With his bookstore chain, he now seems to be admitting that if Amazon is to expand its share of the book market, it will need to invest in bricks as well as bits. Beyond the business rationale, it's hard not to see a certain vindictiveness to Amazon's move. Having come up short in its plan to supplant books and bookstores with digital alternatives, the company is taking its revenge by attacking traditional bookshops on their own turf. Unlike the mom-and-pop independents, or even the struggling Barnes & Noble chain, Amazon has the scale and the cash required to wage a war of attrition. It can sustain losses on its stores for a long time. Bezos may love books, but what he loves even more is the idea of total victory, with no survivors among the vanquished.

The limits of online retail

Amazon Books may be just the vanguard of a much broader push into brick-and-mortar retailing by the company. In October, the *Wall Street Journal* revealed that Amazon is planning to open a chain of convenience stores, mainly for groceries, along with drive-in depots where consumers will be able to pick up merchandise ordered online. It has also begun rolling out small "pop-up" stores to hawk its electronic devices. It already has more than two dozen such kiosks in malls around the country, and dozens more are said to be in the works.

Even after 20 years of rapid growth, e-commerce still accounts for less than 10 percent of total retail sales. And now the rise of mobile computing places new constraints on Web stores. They can't display or promote as many products as they could when their wares were spread across desktop or laptop monitors. That limits the stores' cross-selling and upselling opportunities and blunts other merchandising tactics.

At the same time, the smartphone, with its apps, its messaging platforms, and its constant connectivity, gives retailers more ways to communicate with and influence customers, even when they're shopping in stores. This is why the big trend in retailing today is toward "omnichannel" strategies, which blend physical stores, Web stores, and mobile apps in a way that makes the most of the convenience of smartphones and overcomes their limitations. Some omnichan-

nel pioneers, like Sephora, Best Buy, and Nordstrom, come from the brick-and-mortar world. But others, like Warby Parker and Bonobos, come from the Web world. Now, with its physical stores, Amazon is following in their tracks. "Pure-play Web retailing is not sustainable," New York University marketing professor Scott Galloway told me. He points out that the deep discounting and high delivery costs that characterize Web sales have made it hard for Amazon to turn a profit. If Amazon were to remain an online-only merchant, he says, its future success would be in jeopardy. He believes the company will end up opening "hundreds and then thousands of stores."

Beyond its expertise in Web sales, Amazon brings distinctive strengths to an omnichannel operation. Its vast, efficient network of warehouses and distribution centers can supply outlets and process returns. It has, thanks to the largesse and patience of its investors, a reservoir of cheap capital that it can draw on to fund a building spree. And it has a much-admired brand. What Amazon lacks is experience in the touchy-feely world of traditional retailing. The company's proficiency in software and data crunching is unquestioned. Its people skills are another matter.

Variable prices

The Seattle store sits between a Tommy Bahama and a tanning salon at the southwest corner of the upscale, open-air University Village mall. The exterior is clad in brick, with black-metal moldings around the windows. The floor is hardwood—handsome tea-colored planks. The shelves and tables are built of thick, grainy boards. Even the big TV monitor up front is encased in a wooden frame. The lighting is bright, the signage crisp. Neither cozy nor trendy, neither retro nor modern, the space is pleasant without being distinctive. It suits the mall setting.

As I walk around, I overhear another clerk tell a customer that Amazon Books is "all about browsing." But that's not the way it feels to me. The narrow aisles and the head-high shelves, with all those outward-facing covers, produce a mild claustrophobia that discourages leisurely shopping. And the relatively small selection of high-ranking books, all arrayed in uniform rows, sends a message of fungibility. Every choice seems equally safe, a data-sanctioned "good read." (The four-star cutoff tends to filter out the controversial and the experimental.) Despite a few armchairs and a long bench along one wall, the shop has a grab-and-go vibe, not much different from that of an airport bookstore.

The most distinctive feature of Amazon Books lies not in its design or its merchandising or even its technology—the tech seems about on par with what you'd find at a Starbucks—but in its approach to pricing. There are no price tags on the books, and what customers pay depends on whether or not they're enrolled in the Amazon Prime loyalty program. Those without a Prime membership pay the list price. Those with Prime pay Amazon's discounted online price. To find out what that price is at the moment, you have to carry a book to one of several bar-code-scanning stations set up around the store. Scan the code on the back cover, and the price is revealed on a screen. (As an alternative, you can scan a code on the book's shelf placard with an Amazon app on your phone; that brings up the book's page, with its current price, on the Amazon site.) The process is cumbersome, but it hints at what is probably another of the store's goals: to promote the Prime program, which is central to Amazon's strategy of locking in customers.

Having spent nearly an hour in amateur black-ops mode, taking photos and scribbling notes, I sense that the clerks are eyeing me with suspicion. Not wanting to blow my cover, I decide I should buy something and leave. I grab a copy of Joan Didion's *Slouching Towards Bethlehem* (4.3 stars) and take it to a small checkout area tucked away near the cookbook section. A sign in front of the registers informs me that I have the option of paying with my phone, but that would require launching an app, scanning yet another code, and then handing the phone to the checkout clerk. It seems simpler to swipe a credit card. Not being a Prime member, I pay full retail: 15 bucks, plus tax.

Outside, it has started to rain. I summon an Uber and sit in the back as the driver follows the route on his smartphone over the Montlake Bridge and through the city to the Courtyard by Marriott where I'm staying. Going up to my room holds little appeal, so I head into the lounge, order a vodka, and flip through my e-mails. Over the bar are three TVs, each tuned to a different ball game. I feel let down. I had convinced myself that I was going to witness something fresh and unexpected at Amazon Books. What I found was an annex to a website—a store that, despite the bricks and paper, retains the coldness of the virtual.

Nicholas Carr's most recent book is the essay collection Utopia Is Creepy.

Mr. Robot Killed the Hollywood Hacker

The popular portrayal of computers as magic boxes capable of anything has done real societal harm. Now one TV show wants to save us.

By Cory Doctorow

For decades Hollywood has treated computers as magic boxes from which endless plot points could be conjured, in denial of all common sense. TV and movies depicted data centers accessible only through undersea intake valves, cryptography that can be cracked through a universal key, and e-mails whose text arrives one letter at a time, all in caps. "Hollywood hacker bullshit," as a character named Romero says in an early episode of *Mr. Robot,* now in its second season on the USA Network. "I've been in this game 27 years. Not once have I come across an animated singing virus."

Mr. Robot marks a turning point for how computers and hackers are depicted in popular culture, and it's happening not a moment too soon. Our thick-headedness about computers has had serious ramifications that we've been dealing with for decades.

Following a time line of events from about a year before the air date of each episode, *Mr. Robot* references real-world hacks, leaks, and information security disasters of recent history. When hackers hack in *Mr. Robot*, they talk about it in ways that actual hackers talk about hacking. This kind of dialogue should never have been hard to produce: hacker presentations from Black Hat and Def Con are a click away on YouTube. But *Mr. Robot* marks the first time a major media company has bothered to make verisimilitude in hacker-speak a priority.

The show excels not only at talk but also at action. The actual act of hacking is intrinsically boring: it's like watching a check-in clerk fix your airline reservation. Someone types a bunch of obscure strings into a terminal, frowns and shakes his head, types more, frowns again, types again, and then smiles. On the screen, a slightly different menu prompt represents the victory condition. But the show nails the *anthropology* of hacking, which is fascinating as all get-out. The way hackers decide what they're going to do, and how they're going to do it, is unprecedented in social history, because they make up an underground movement that, unlike every other underground in the past, has excellent, continuous, global communications. They also have intense power struggles, technical and tactical debates, and ethical conundrums—the kind of things found in any typical *Mr. Robot* episode.

Mr. Robot wasn't the first technically realistic script ever pitched, but it had good timing. In 2014, as the USA Network was deliberating over whether to greenlight *Mr. Robot*'s pilot for a full season, Sony Pictures Entertainment was spectacularly hacked. Intruders dumped everything—prerelease films, private e-mails, sensitive financial documents—onto the Web, spawning lawsuits, humiliation, and acrimony that persists to this day. The Sony hack put the studio execs in a receptive frame of mind, says Kor Adana, a computer scientist turned screenwriter who is a writer and technology producer on the series. Adana told me the Sony hack created a moment in which the things people actually do with computers seemed to have quite enough drama to be worthy of treating them with dead-on accuracy.

It's about time. The persistence until now of what the geeks call "Hollywood OS," in which computers do impossible things just to make the plot go, hasn't just resulted in bad movies. It's confused people about what computers can and can't do. It's made us afraid of the wrong things. It's led lawmakers to create a terrible law that's done tangible harm.

Worst law in technology

In 1983, Matthew Broderick had his breakout role as David Lightman, the smart, bored Seattle teen who entertains himself in *WarGames* by autodialing phone numbers with his computer's primitive modem, looking for systems to hack into and explore. When he connects to a mysterious system—seemingly an internal network for a game development company—he nearly starts World War III, because that "game company" is actually the Pentagon, and the "Global Thermo-

SETH ARMSTRONG

Rami Malek plays Elliot on Mr. Robot*, a show that marks the first time a studio has bothered to prioritize accuracy in how it portrays hacker culture.*

SARAH SHATZ/USA NETWORK

nuclear War" game he's initiated is the autonomous nuclear retaliatory capability designed to launch thousands of ICBMs at the USSR.

WarGames inspired many a youngster to scrounge a 300-baud modem and experiment with networked communications. Linguistically, it gave us "wardialing" (dialing many phone numbers in sequence), which begat "warwalking" and "wardriving" (hunting for open Wi-Fi networks). The film wasn't a terrible approximation of how a misfit kid might have tried to hack in, although *WarGames* did make it seem as if the system had fewer fail-safes than it actually did. (Still, it also appears to be true that in real life the launch code for all the missiles was set to "00000000.")

The worst thing about *WarGames*—and its most profound legacy—was the reaction of panicked lawmakers.

Passed by Congress in 1984 and broadened in 1986, the Computer Fraud and Abuse Act was a sweeping anti-hacking bill inspired by the idea that America's Matthew Brodericks could set off Armageddon. Before CFAA's passage, prosecutions against hackers had invoked a hodgepodge of legal theories. Crooks who broke into sensitive databases were charged with theft of the electricity consumed in the transaction.

CFAA's authors understood that even if they explicitly banned the hacking techniques of the time, these prohibitions would swiftly be overtaken by advances in technology, leaving future prosecutors scrounging for legal theories again. So CFAA took an exceptionally broad view of what constitutes criminal "hacking," making a potential felon out of anyone who acquires unauthorized access to a computer system.

It sounds simple: you can legally use a computer only in ways its owner has permitted. But CFAA has proved to be a pernicious menace—what legal scholar Tim Wu has called "the worst law in technology." That's because companies (and federal prosecutors) have taken the view that your "authorization" to use an online service is defined by its end-user license agreement—the thousands of words of legalese that no one ever reads—and that violating those terms is therefore a felony.

This is how a young entrepreneur and activist named Aaron Swartz came to be charged with 13 felonies after using a script to automate his downloads of articles from JSTOR, a scholarly repository on MIT's networks. Swartz was legally permitted to download these articles, but the terms of service forbade using a script to fetch them in bulk. What Swartz did was no accident—he made multiple attempts to get around JSTOR's download limits over a period of months, and ultimately entered a basement wiring closet to tap into a network switch directly. But because of CFAA he was facing up to 35 years in prison when he hanged himself in 2013.

After *WarGames*, Hollywood made a trickle of "hacker movies," many much beloved by actual hackers. There was 1992's *Sneakers*, which took some of its inspiration from real-world phone phreaks John "Cap'n Crunch" Draper and Josef "Joybubbles" Engressia. There was 1995's *Hackers*, which referenced the 2600: Hacker Quarterly meetups and Operation Sundevil, the Secret Service's notorious 1990 hacker raids (which resulted in the founding of the Electronic Frontier Foundation).

But even these movies wanted for much in the way of technical accuracy.

Mr. Robot
USA Network

Black Mirror
Britain's Channel 4

The Computer Fraud and Abuse Act

Sneakers ridiculously featured a universal key that can break all crypto; *Hackers* featured the graphically elaborate virus mocked by Romero in *Mr. Robot*. The musical viruses and absurd user interfaces in these hacker films of the 1990s are the desperate hallmarks of a visual medium trying to make a nonvisual story interesting.

It only got worse. As cryptography crept into the public eye—first through the mid-1990s debate over the Clipper Chip, which would have put a backdoor in essentially all computers, and then through subsequent political fights that rage on to this day—it became a frequent source of plot points and groans of dismay from actual hackers and security experts. Like the moment in the fifth *Mission Impossible* movie when hackers replace the contents of an encrypted file with 0s without first decrypting the file, or the way in *Skyfall* that encrypted data is visualized as a giant moving sphere. Crypto in movies works just like crypto in the minds of lawmakers: perfectly, until it needs to fail catastrophically.

Fan noise

Kor Adana is largely responsible for giving *Mr. Robot* the technological rigor that sets the show apart. The 32-year-old Michigan native once worked at an automotive company, attempting to punch holes in the security of the computers in cars heading into production.

Adana told me that when he threw away his lucrative cybersecurity career to work in Hollywood, he was gambling that his background in information security would be an asset rather than an odd quirk. That paid off thanks to the trust of show creator Sam Esmail, who gave Adana the authority to argue with production designers over seemingly minor details. He ensures that the correct cable connects a PC tower to its monitor, or that the network card's activity lights are actually blinking when the shot comes out of post-production. Adana gives sound engineers fits by insisting that scenes set in rooms full of powerful PCs must have the correct level of accompanying fan noise.

Adana also battles the legal department over his commitment to technical rigor in the hacking attacks depicted on the show, knowing that hackers will go through the episode frame by frame, looking at the command-line instructions for accuracy and in-jokes. Those hackers are a minority of the show's audience, but they're also the show's cheerleaders, and when an incredulous information civilian asks a clued-in hacker buddy whether the stuff on *Mr. Robot* could *really* happen, the hacker can nod vigorously and promise that it's all true.

Decades ago, *WarGames* inspired a legacy of stupid technology law that we still struggle with. *Mr. Robot* might just leave behind a happier legacy.

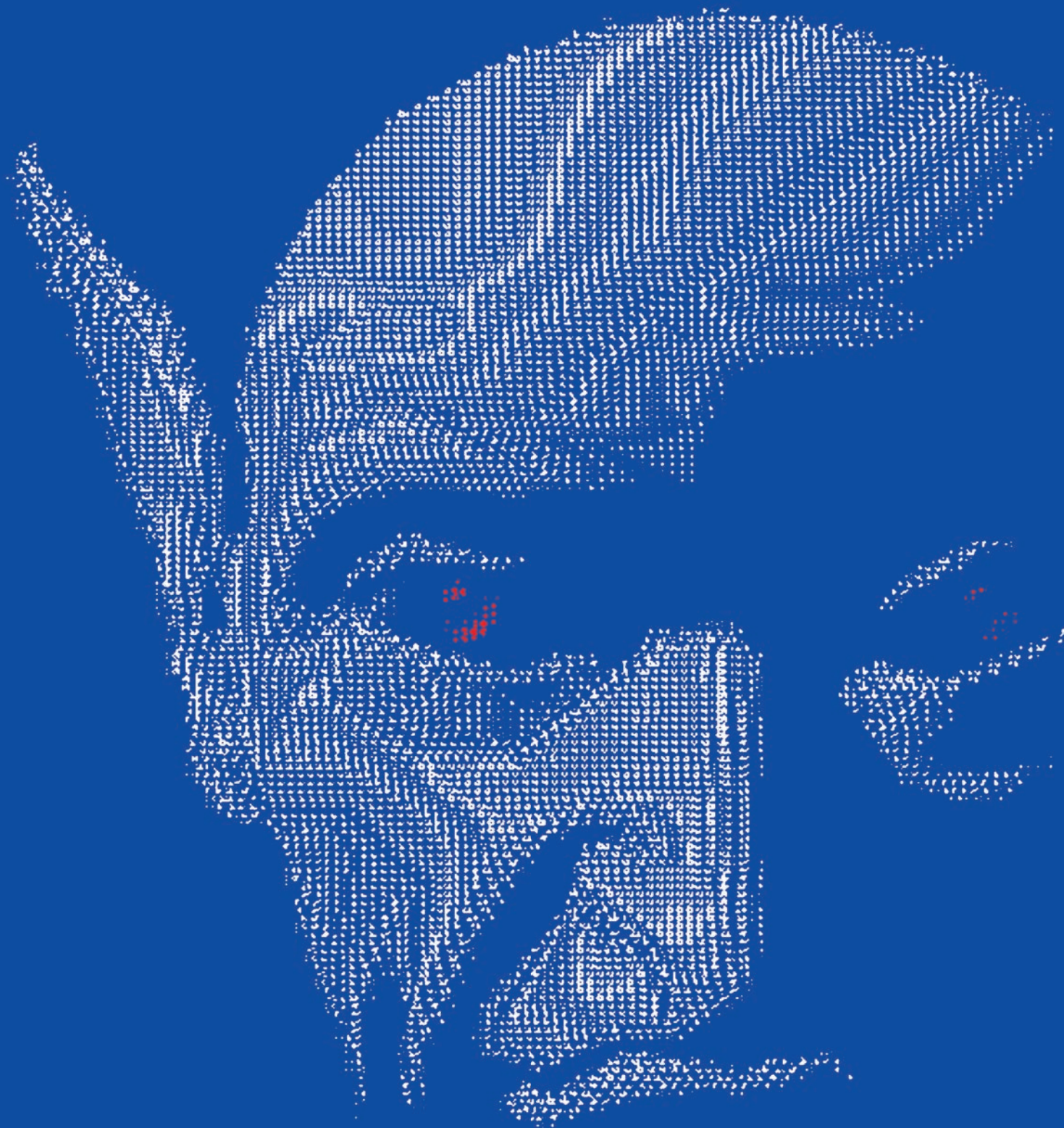
Another promising show is *Black Mirror*, created by the British satirist Charlie Brooker and now streaming on Netflix. It's not rigorous in the same way as *Mr. Robot*, because it projects into the future rather than describing the technical details of the recent past. But its depiction of user interface elements and product design reflect a coherent understanding of how the technologies of today work, and thus where they may be tomorrow. Clicks on computers in the show call forth menus that have options we can recognize; the opacity of the error messages is all too familiar; even the vacant facial expressions of people lost in their technology have a plausibility that other shows rarely achieve.

My own 2008 young adult novel *Little Brother*, whose plot turns on the real capabilities of computers, has been under development at Paramount for a year now. The story features a teenage hacker army that uses GPS to send private e-mails and exploits software-defined radios in game consoles to create mesh networks protected by strong crypto. The one thing everyone in the meetings agrees on is that the technical rigor of the story needs to be carried over onto the screen.

This isn't trivial. It's not just about better entertainment. When information security is the difference between a working hospital and one that has to be shut down (as was the case with the ransomware attacks on hospitals across America in 2016) and when server break-ins can affect the outcomes of U.S. elections, it's clear that we all need a better sense of what computers can do for us and how they can burn us. Adana says he is gratified when he meets information security noncombatants who have no interest in being IT nerds but who *are* interested in the security and privacy implications of the technologies they use—something heretofore believed to be impossible.

Information security is one of those problems whose very nature can't be agreed upon—and the lack of technological smarts in the halls of power is compounded by the lack of technological understanding in the body politic. Decades ago, *WarGames* inspired a legacy of stupid technology law that we still struggle with. *Mr. Robot* and the programs that come after it might just leave behind a happier legacy: laws, policies, and understanding that help us solve the most urgent problems of our age.

Cory Doctorow is a science fiction novelist; his next book, Walkaway, *will be published in 2017. He is also a special advisor to the Electronic Frontier Foundation and activist in residence for the MIT Media Lab.*



If Only AI Could Save Us from Ourselves

Google has an ambitious plan to use artificial intelligence to weed out abusive comments and defang online mobs. The technology isn't up to that challenge—but it will help the Internet's best-behaving communities function better.

By David Auerbach

Humans have broken the Internet. Cyberbullying, harassment, social shaming, and sheer unpleasantness plague such sites as Twitter and Reddit, especially if you happen to attract the wrong sort of attention. Consider the way *Ghostbusters* star Leslie Jones and public relations executive Justine Sacco became targets for mass abuse.

The companies that run online services are typically squeezed between charges of indifference to harassment and suppression of free speech. But now Google thinks it can use artificial intelligence to lessen this tragedy of the digital commons. (Disclosure: I worked for Google in the 2000s.) A technology incubator in the company, called Jigsaw—formerly known as Google Ideas—says it intends to spot and remove digital harassment with an automated program called Conversation AI. As Jigsaw's president, Jared Cohen, told *Wired*, "I want to use the best technology we have at our disposal to begin to take on trolling and other nefarious tactics that give hostile voices disproportionate weight, [and] to do everything we can to level the playing field."

Conversation AI
from Google's Jigsaw

It's gutsy for Google to take this on, and it's different from some of Jigsaw's previous work. That has included Project Shield, which protects news sites and sites promoting freedom of expression against denial-of-service attacks. Another Jigsaw effort, Password Alert, is a Chrome extension that guards against phishing attacks. Those were primarily technical challenges. But fighting trolls and online mobs is also a sociological problem.

Conversation AI is an offshoot of one of the most successful of Google's "moonshot" projects, Google Brain. It has helped revolutionize the field of machine learning through large-scale neural networks, and given Google advantages such as software that is more skillful than humans at recognizing images. But Conversation AI won't be able to defeat online abuse. Though Jigsaw's stated goal is to "fight the rise of online mobs," the program itself is a far more modest—and therefore more plausible—project. Conversation AI will primarily streamline the community moderation that is today performed by humans. So even if it is unable to neutralize the worst behavior online, it might foster more and better discourse on some sites.

Allusion detection

Jigsaw is starting Conversation AI at the *New York Times*, where it will be rolled out in a few months to help the company manage its online comments. Human moderators currently review nearly every comment published on the site. Right now, Conversation AI is reading 18 mil-

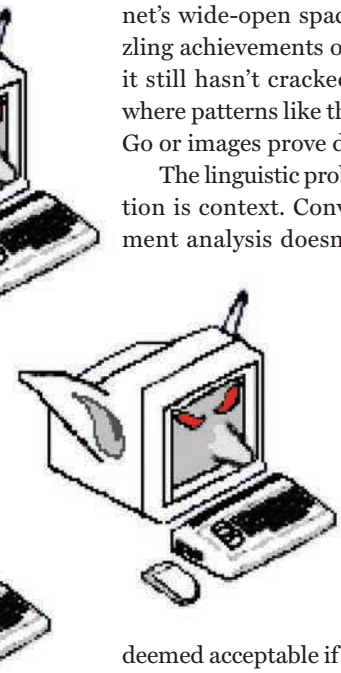
ERIK CARTER

lion of them, learning to detect each individual category of comments that get rejected—insubstantial, off-topic, spam, incoherent, inflammatory, obscene, attack on commenter, attack on author, attack on publisher.

The *Times*'s goal is not necessarily to reduce abuse in its comments, a problem it already considers under control. Instead, it hopes to reduce the human moderators' workload. "We don't ever expect to have a system that's fully automated," Erica Greene, engineering manager of the *New York Times* community team, told me. *Times* community editor Bassey Etim estimates that somewhere between 50 and 80 percent of comments could eventually be auto-moderated, free-

ing up employees to devote their efforts to creating more compelling content *from* the paper's comment sections.

The *New York Times* site poses very different problems from the real-time free-for-all of Twitter and Reddit. And given the limitations of machine learning—as it exists today—Conversation AI cannot possibly fight abuse in the Internet's wide-open spaces. For all the dazzling achievements of machine learning, it still hasn't cracked human language, where patterns like the ones it can find in Go or images prove diabolically elusive.



The linguistic problem in abuse detection is context. Conversation AI's comment analysis doesn't model the entire flow of a discussion; it matches individual comments against learned models of what constitute good or bad comments. For example, comments on the *New York Times* site might be deemed acceptable if they tend to include common words, phrases, and other features. But Greene says Google's system frequently flagged comments on articles about Donald Trump as abusive because they quoted him using words that would get a comment rejected if they came from a reader. For these sorts of articles, the *Times* will simply turn off automatic moderation.

It's impossible, then, to see Conversation AI faring well on a wide-open site like Twitter. How would it detect the Holocaust allusions in abusive tweets sent to the Jewish journalist Marc Daalder: "This is you if Trump wins," with a picture of a lamp shade, and "You belong here," with a picture of a toaster oven? Detecting the abusiveness relies on historical knowledge and cultural context that a machine-learning algorithm could detect only if it had been trained on very similar examples. Even then, how would it be able to differentiate between abuse and the same picture with "This is what I'm buying if Trump wins"? The level of semantic and practical knowledge required is beyond what machine learning currently even aims at.

Consequently, a dedicated Twitter troll will no doubt find a novel way of expressing abuse that evades a system like Conversation AI. By blocking some comments, machine learning could do a decent job of getting commenters to stop casually calling each other "fags" and "homos," if that's the goal. But machine learning will not be able to foil a person hell-bent on insinuating that someone is queer.

In other words, Conversation AI will enable moderation tasks to be executed more efficiently in communities that already tend to be pretty well behaved. It is incapable of rooting out the worst of the abuse we hear about, which frequently shows up on sites with minimal moderation standards. Policing abuse on Twitter and Reddit is impossible without fundamentally altering the nature of those platforms.

Policing abuse on Twitter and Reddit is impossible without fundamentally altering the nature of those platforms.

Gated communities

Facebook's success is a reminder that most people, and certainly most companies, prefer a relatively sheltered and controlled environment to one where strangers can intrude into others' business and start fights. So if Conversation AI or similar tools make it easier and more efficient to exercise such control, it's a reminder that "solving" the abuse problem, whether through human or automated means, requires moving away from maximal inclusivity as the highest ideal online. Even seemingly "open" communities such as StackExchange and MetaFilter require constant moderator intervention and community policing. Truly anarchic communities, such as Twitter, 4chan, and some channels on Reddit, prove to be the exceptions online, not the rule. Nor are anarchic communities moneymakers. Twitter has had trouble attracting a buyer, partly because of its reputation for abusive content, while Reddit has had a high degree of staff turnover and difficulties monetizing. The Wild West nature of those sites will become only more apparent if tools like Conversation AI make moderated sites function even better.

It's worth noting one big potential downside. Because Conversation AI is being trained to approve content that hews to certain lexical, grammatical, and stylistic guidelines, it won't just filter out abusive content. It could also tend to strike *diverse* content. That raises questions of what censorship-minded governments could do with it. Just as the *Times* curates its communities, so too can the governments of Turkey and China curate theirs. While Jigsaw efforts like Project Shield aim to provide defenses for politically sensitive websites, Conversation AI makes it easier to filter out unwanted speech—but the question is, unwanted by whom? There is no label on the box that says, "Use only to prevent abuse."

David Auerbach is writing a book on human and computer languages and their convergence, to be published by Pantheon. He worked for 11 years as a software engineer at Google and Microsoft, primarily in server infrastructure.

Demo

Meet the Octobot

Researchers use an ingenious design to make a soft robot that moves on its own.

By Julia Sklar
Photographs by Adam DeTour

1 A researcher measures a silicone mixture that will form the body of the octobot.

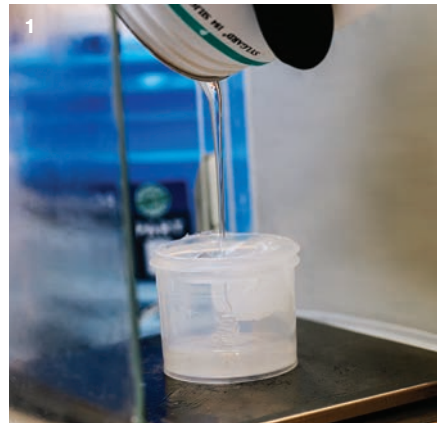
2 A platinum ink is prepped for extrusion through a 3-D printer.

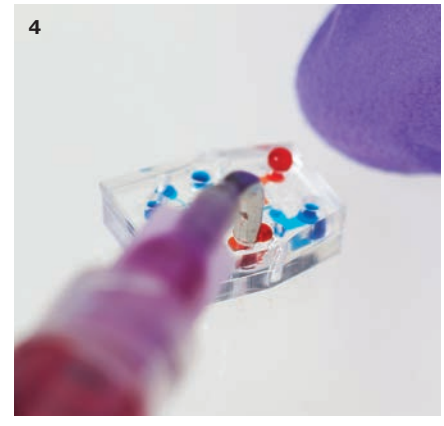
3 Molds like this are used to form the robot's distinctive shape.

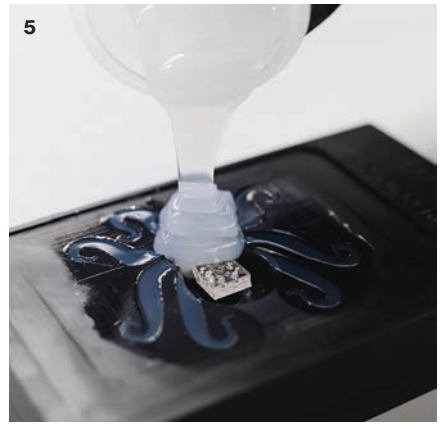
4 At the center of the octobot is a soft microfluidic chip, which acts as the bot's "brain," directing the motion of all eight tentacles.

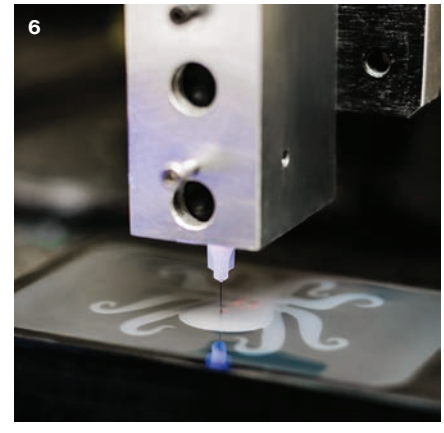
5 The first step in assembly is pouring the silicone mixture into the mold.

6 Next, a 3-D printer squeezes out lines of ink, which will be suspended in the silicone body. The platinum ink will help turn liquid hydrogen peroxide into gas to move the tentacles; another ink will pave the way for vessels throughout the bot that the gas will travel through.









The "octobot" is a squishy little robot that fits in the palm of your hand and looks like something in a goody bag from a child's birthday party. But despite its quirky name and diminutive size, this bot represents an astonishing advance in robotics.

According to the Harvard researchers who created it, it's the first soft robot that is completely self-contained. It has no hard electronic components—no batteries or computer chips—and moves without being tethered to a computer.

The octobot is basically a pneumatic tube with a very cute exterior. To make it move, hydrogen peroxide—much more concentrated than the kind in your medicine cabinet—is pumped into two reservoirs inside the middle of the octobot's body. Pressure pushes the liquid through tubes inside the body, where it eventually hits a line of platinum, catalyzing a reaction that produces a gas. From there, the gas expands and moves through a tiny chip known as a microfluidic controller. It

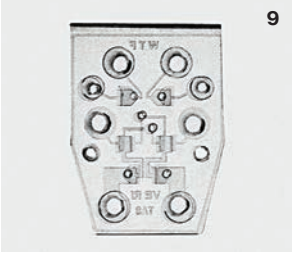
alternately directs the gas down one half of the octobot's tentacles at a time.

The alternating release of gas is what makes the bot do what looks like a little dance, wiggling its tentacles up and down and moving around in the process. The octobot can move for about eight minutes on one milliliter of fuel.

So how do you even build something like this? "You have to make all the parts yourself," says Ryan Truby, a graduate student in Jennifer Lewis's lab at Harvard,

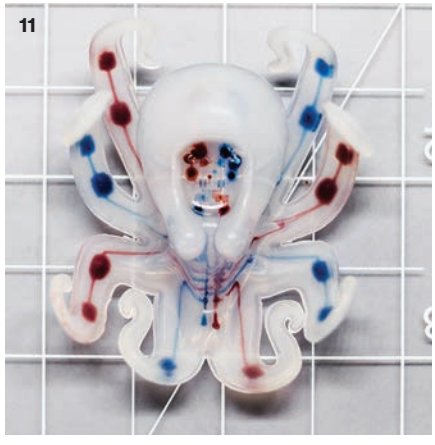
7 The full array of tools and molds the researchers use to create these bots. It took 300 tries to get the octobot to work.

8 The mill used to create the octobot mold.

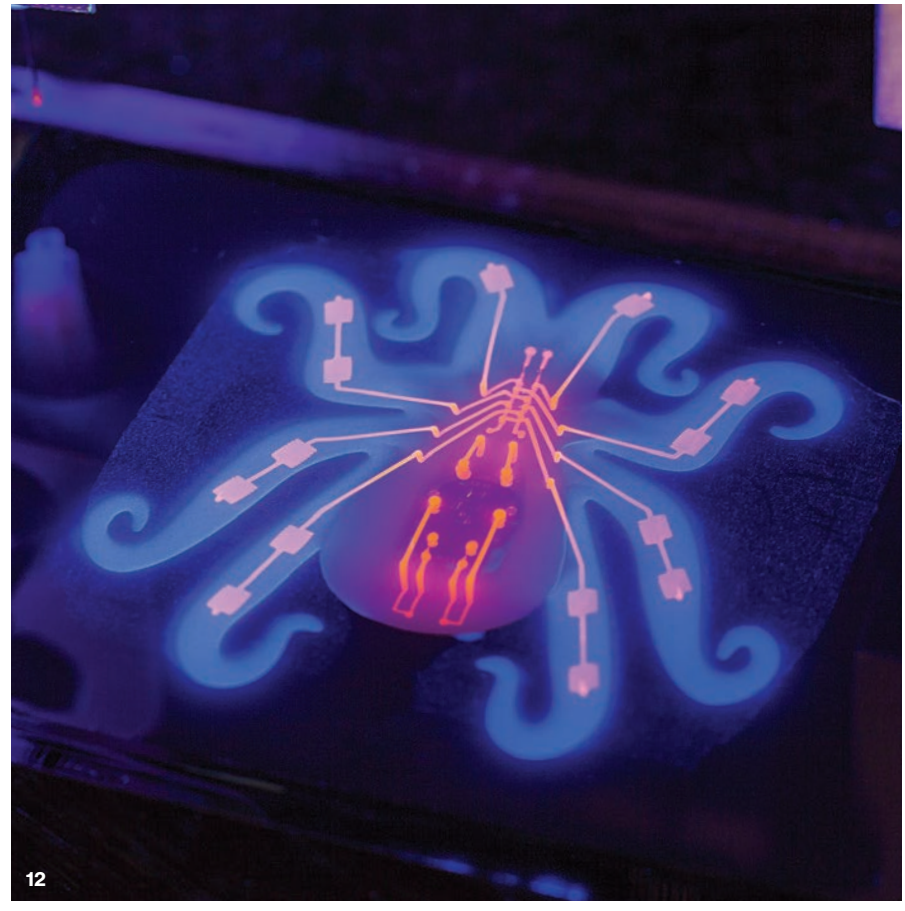


9 A close-up of the microfluidic chip that goes inside the bot.

10 The octobot is usually colorless. Flashy dyes are sometimes added for illustrative purposes.



11 The colors here show the alternating routes that the gas can take through the bot, moving half of the tentacles at a time and helping it wiggle. The bot is about two inches long.



12 Just for fun, the ink can glow under a black light.

"You have to make all the parts yourself."

where the materials half of this research is taking place. The mold for the octopus shape and the microfluidic chip were among the things developed nearby in Robert Woods's lab.

The octobot is made out of materials that most microfluidics labs have on hand. But it took the researchers 300 tries to get the recipe right. First they place a microfluidic chip in an empty, custom-made octopus mold. Then they pour a silicone mixture into the mold, covering the chip. After they use a 3-D printer to inject lines of ink into the silicone, they bake it for four days. This seals the shape of the octobot and makes one of the inks evaporate, leaving behind hollow vessels through which the pressurized gas will flow.

Still missing are sensing and programming abilities that would afford more control over the robot's movement. But the octobot is purposefully minimalist, meant just to show that such a soft robot can be made at all.

37 Years Ago

How to Fix Democracy

A computer scientist who saw congressional decision-making up close in 1980 found it insufficient to the task of solving big problems.

"I've heard many times that although democracy is an imperfect system, we somehow always muddle through. The message I want to give you, after long and hard reflection, is that I'm very much afraid it is no longer possible to muddle through. The issues we deal with do not lend themselves to that kind of treatment. Therefore, I conclude that our democracy must grow up. I'm not going to give you a magic recipe on how that will happen—I wish I had one—but I offer some thoughts that I hope will stimulate your thinking.

What's principally lacking on the federal scene, it seems to me, is the existence of respected, nonpartisan, interdisciplinary teams that could at least tell us what is possible and something about the pluses and minuses of different solutions. Take energy, for instance. What I would love to see established, with the National Academies or any other mechanism to confer respectability, is a team that will … say, 'Okay, there are lots of suggestions around, and most of them won't work. But here are six different plans, any one of which is possible. We'll tell you what each one costs, what's good about it, what's bad about it, how dangerous it is, and what its uncertainties are.' At least each option would be a well-integrated, clearly thought-out plan. I do not trust democracy to try to put together such a plan by having each committee of Congress choose one piece of it. Suppose Congress designed an airplane, with each committee designing one component and an eleventh-hour conference committee deciding how the pieces should be put together. Would you fly on that airplane? I am telling you we are flying on an energy plan, an inflation plan, and so on that are being put together in exactly that way.

The present system does not work. It was designed for a much earlier and simpler age. I believe that Jeffersonian democracy cannot work in the year 1980—the world has become too complex. I'm not advocating the abolition of democracy. What l am advocating is its salvation. And the only way to save American democracy is to change the fundamental decision-making process, at the federal level, so that it can come to grips with the enormous and complex issues that face this nation."

Excerpted from "Saving American Democracy: The Lessons of Three Mile Island," by John G. Kemeny, from the June/July 1980 issue of Technology Review.

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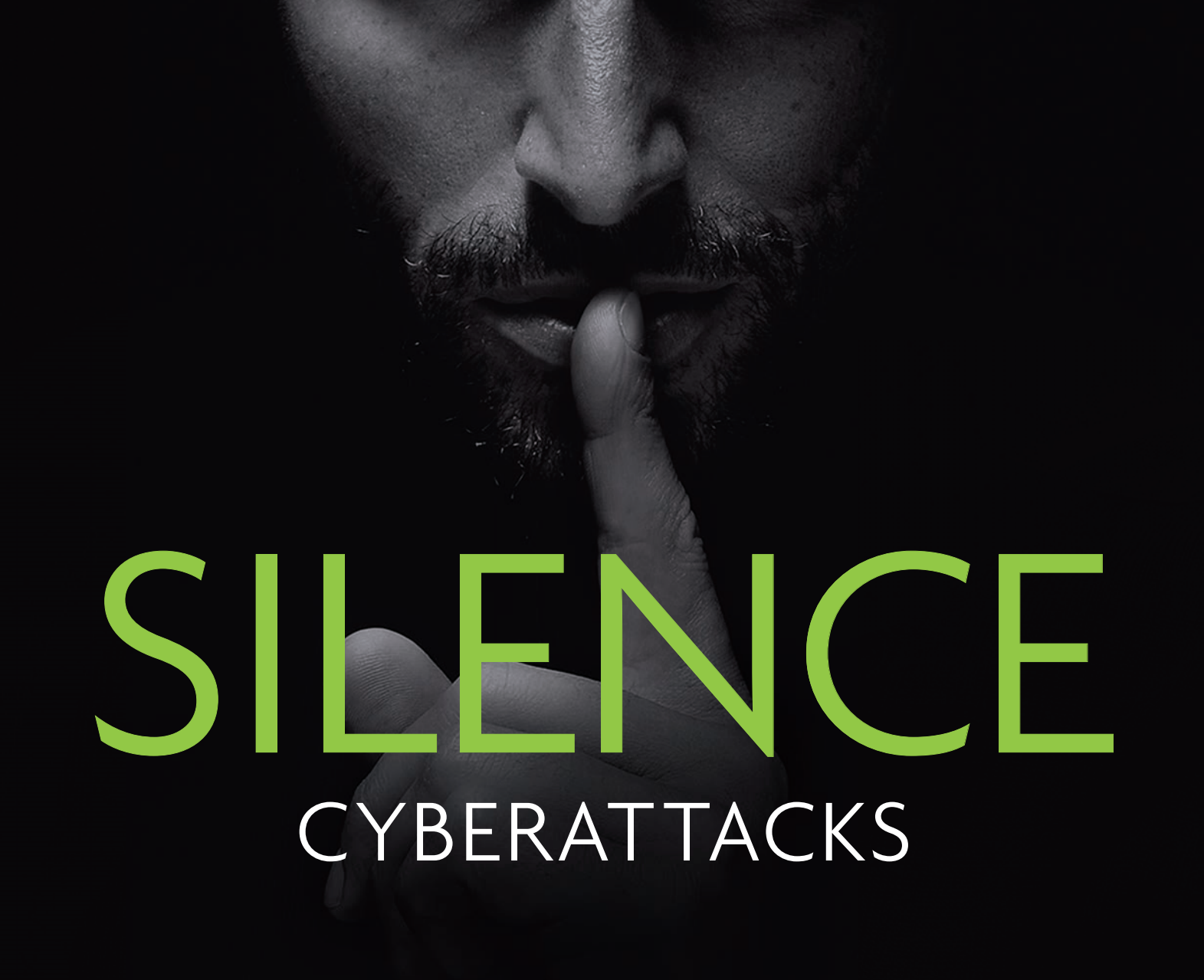

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